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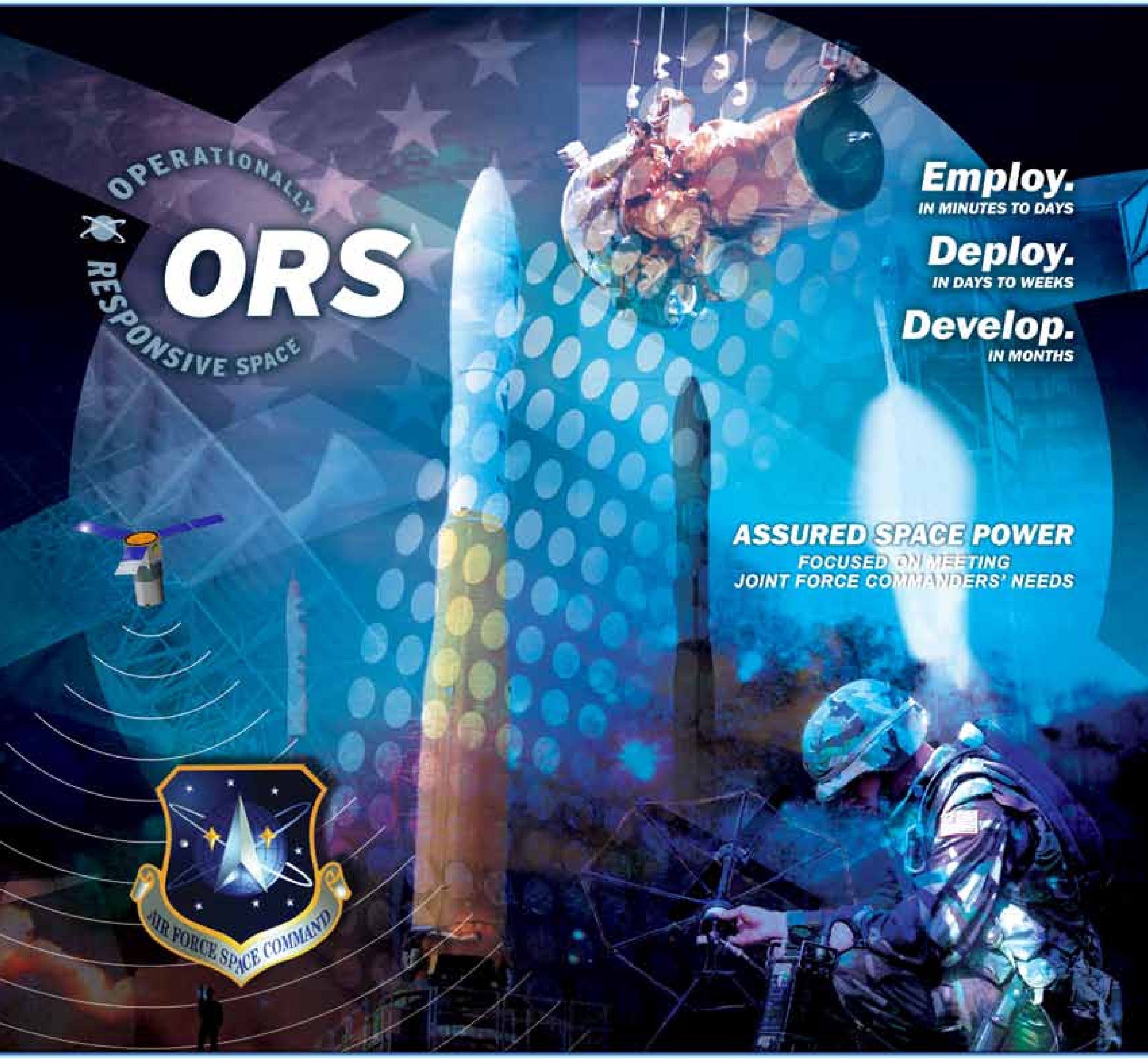

OPERATIONALLY RESPONSIVE SPACE

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Contents

Next Issue:

Space and Cyberspace: Complementary?

Introduction

General C. Robert Kehler
Commander, Air Force Space Command

Joint force commanders rely on space and cyberspace capabilities to help create the effects they need across the spectrum of conflict. The asymmetrical threats and challenges we face require that we constantly explore new and more effective ways to meet the needs our joint commanders demand.

As space systems have grown to provide more detailed and diverse services more quickly and more frequently, they have been integrated ever more tightly with real-time military planning and operations. Today, space capabilities are embedded in a host of systems serving forces and commanders at every level. Space is no longer just the high ground; it is an integral part of joint operations. Operational plans and advanced weapons depend on space as never before, and military plans must take into account potential loss of capability by space assets due to mischance or hostile action. Military forces demand space systems to provide timely and continuing support to joint force commanders in peace, crisis, and war. Our forces demand space systems for use in training and exercises, and whose products and services can also be extended to our allies and coalition partners. US forces increasingly need a space architecture responsive to military purposes that can support operational plans. They demand capabilities that are configured to optimally serve tactical needs and that can continue to contribute to the joint fight, even when under duress.

As we move forward, we need to determine the optimal space architecture to accommodate joint force operational and tactical needs without sacrificing the capabilities and support required to meet our national and strategic challenges. This quarter's *High Frontier Journal* is focused on the subject of "Operationally Responsive Space." Preeminent representatives from government, academia, and industry have weighed in and provide some perceptive and thought provoking ideas on how we can best meet the joint commander's needs for responsive space capabilities through an evolution in our space architecture and a modification in our approach to the acquisition and operations of future systems.

This issue of the *High Frontier Journal* provides arguments for increased and continued partnership internationally, intragovernmentally and with our industrial base. Many articles encourage continued and more diligent focus to expand and adapt our space architecture to include smaller, more tailored, and thus more operationally responsive systems. The authors address the need to adapt and improve upon our existing processes and rethink how we approach risk tolerance and warfighter need in a more responsive and adaptable space architecture. Many authors also highlight lessons learned from our recent experiences in providing operationally responsive capability, as well as discuss areas that are ripe for improvement especially in acquisition, operational constructs, risk aversion, and potential partnerships. Finally, and perhaps most importantly, it is clear that our contributors recognize that operationally responsiveness is a mindset—maybe best achieved by adapting or adjusting systems already in orbit.

Technology advancement will continue to alter the nature of the capabilities possible through space and conversely the ability of the adversary to deny these capabilities. Therefore, it is imperative for the joint fight that we continue to drive advancement and technology development that is focused on responsive and assured space capabilities. I hope these articles foster discussion on the contemporary problems of meeting operational space demands and the opportunities and challenges we will continue to face in the future.

Our next issue will explore the potential synergies and complementary aspects of the space and cyberspace warfighting domains. It will explore possible synergies between space and cyberspace and the organizational roles and responsibilities that would best provide mission assurance in both domains. I look forward to the perspectives and ideas that will be shared by the distinguished group of experts we have invited to participate.

General C. Robert "Bob" Kehler (BS, Education, Pennsylvania State University; MS, Public Administration, University of Oklahoma; MA, National Security and Strategic Studies, Naval War College, Newport, Rhode Island) is commander, Air Force Space Command (AFSPC), Peterson AFB, Colorado. He is responsible for organizing, equipping, training and maintaining mission-ready space and cyberspace capabilities for North American Aerospace Defense Command, US Strategic Command (USSTRATCOM), and other combatant commands around the world. General Kehler oversees Air Force network operations; manages a global network of satellite command and control, communications, missile warning and space launch facilities; and is responsible for space system development and acquisition. He leads more than 46,000 professionals, assigned to 88 locations worldwide and deployed to an additional 35 global locations.

General Kehler has commanded at the squadron, group, and twice at the wing level, and has a broad range of operational and command tours in ICBM operations, space launch, space operations, missile warning, and space control. The general has served on the AFSPC staff, Air Staff, and Joint Staff and served as the director of the National Security Space Office. Prior to assuming his current position, General Kehler was the deputy commander, USSTRATCOM, where he helped provide the president and secretary of defense with a broad range of strategic capabilities and options for the joint warfighter through several diverse mission areas, including space operations, integrated missile defense, computer network operations, and global strike.

Senior Leader Perspective

Operationally Responsive Space and the National Security Space Architecture

Lt Gen John T. Sheridan, USAF
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For nearly 60 years, the US has led the world in space systems. We have successfully designed, produced, fielded, and sustained robust space capabilities spanning multiple missions, such as communication; intelligence, surveillance, and reconnaissance; warning; precision, navigation, and timing; command and control; and environmental monitoring. Unquestionably, these assets have become an integral part of our national warfighting architecture.

In many cases, these robust "big space" capabilities started as developmental, "small space" efforts that incorporated innovative approaches to advancing state-of-the-art. "Small space" is not just scaled-down payloads, satellites, or launch vehicles, but rather innovative, evolutionary, and sometimes high risk efforts that build on existing or new capabilities. Yesterday's science projects morphed into today's architecture through the use of targeted science and technology investments, government and industry partnerships, ride sharing, and even experimental satellites.[1]

Over time, we have built and benefited from a research, development, test, and evaluation infrastructure that specializes in development of high risk, high reward experiments that demonstrate viable space capabilities. This targeted spirit of innovation resulted in the successful development of our national security space architecture, providing a distinct strategic advantage that we continue to exploit.

Our national security space architecture provides products and services for operational use in ongoing contingency operations, but greater responsiveness is required. Demand for imagery and bandwidth is growing. Technological advances on the battlefield are driving an insatiable demand for space capabilities that, in turn, drives a need for greater responsiveness. Joint force commanders also fear that space capabilities that are heavily relied upon by warfighters might not be available when needed most. We have seen foreign development and employment of an array of capabilities specifically designed to deny the US' use of space. Of particular concern are a variety of physical threats to our space systems that we have not had to consider in the past. In short, space is now a contested environment. As the nation's demands on its military instrument of power have shifted in the 21st century toward defeating a wide range of adversaries—state or non-state actors—with a charge to do so swiftly in overlapping campaigns, it is vital that we are able to augment, replenish or reconstitute space assets to provide responsive capabilities at the operational and tactical levels.

The Department of Defense (DoD) defines operationally responsive space (ORS) as assured space power focused on timely satisfaction of joint force commanders' needs.[2] The warfighting effects that are desired include reconstitution of lost capabilities, augmentation of existing capabilities, filling unanticipated gaps in capabilities, exploiting new technical or operational innovations, and enhancing survivability of space systems. In this context, two essential tasks must be accomplished to achieve ORS. First, we must develop and mature end-to-end ORS enablers that will be required to deliver highly responsive capabilities. The second essential task is to execute rapid end-to-end capability efforts to meet urgent operational needs.

We are off to a great start! The Space and Missile Systems Center is successfully applying our "small space" capabilities as enablers in meeting emerging responsive space needs. Consider for a moment our "small space" efforts in the context of the three tiers of ORS.[3]

For the first tier, we "employ" ORS capability to meet demand with existing assets in a timeframe of minutes to hours. Options range from re-utilizing current space assets on orbit to partnering with commercial entities to meet warfighter needs. We have seen several successful examples of Tier 1 "employment." We are finding better ways to exploit data from existing sources. After we launched Space Based Infrared Systems Highly Elliptical Orbit, also known as SBIRS HEO, we realized the sensors on orbit were performing better than expected. We received funding from Congress for a series of independent projects to exploit the data for operational use, with each project not to exceed 24 months. These are small, one to three million dollar targeted efforts. Through better data exploitation, we find that we're able to get key information to a greater number of operational users more quickly, resulting in earlier missile warning data and enhanced technical intelligence. Additionally, we are seeking partnerships with commercial entities on programs such as Commercially Hosted Infrared Payload (CHIRP) to take advantage of excess payload capacity to attach respon-

Over time, we have built and benefited from a research, development, test, and evaluation infrastructure that specializes in development of high risk, high reward experiments that demonstrate viable space capabilities.

Going forward, an end-to-end series of ORS capabilities should be factored into the overall space architecture and assigned resources based on mission importance and user needs.

sive military sensor packages.

If Tier 1 does not meet the need, we would seek a Tier 2 solution, with "launch or deployment" of on-call assets in a timeframe of days to weeks. Our "small space" efforts already include or have in work a number of enablers that support Tier 2 launch and deployment. Rockets such as Minotaur I and Minotaur IV, built with re-purposed intercontinental ballistic missile components, can be readied for launch relatively quickly and cheaply. A number of commercial entities are working toward faster, less expensive launch services that may provide a viable option for on-call responsive launches. For on-call launch to work, standardized services are becoming available, such as standard interface vehicle, evolved expendable launch vehicle secondary payload adapter, multi-payload adapters, and Hydrazine Auxiliary Propulsion System (HAPS) which can accommodate a variety of multiple payloads.

If an operational need cannot be met with employment of existing systems or launch and deployment of on-call assets, then we must move to Tier 3 "development" of a new or modified capability within a timeframe of months, not years. Operationally Responsive Space Satellite 1 (ORS-1) is a two year developmental effort to meet a central command urgent operational need for an intelligence, surveillance, and reconnaissance (ISR) system capable of direct tasking by DoD. ORS-1 did not come out of a vacuum; again we benefit from previous "small space" efforts. The vehicle is based on our successful Tactical Satellite-3 (TacSat-3) bus mated with an existing airborne ISR sensor, and will be launched on a Minotaur I rocket late this year.

As we work toward development of a robust ORS architecture, we are finding additional value along the way, and have gained a number of key insights in the design and build process. We need to focus on operational capabilities, not single experiments, and consider the transition to operations and sustainment up front. At present, we do not have an operations and maintenance pipeline for these capabilities. An ORS architecture must account for it.

End-to-end, responsive capability will require standardization; standard launchers, payload interfaces, satellite buses, and common ground system architecture. For example, the Multi-Mission Space Operations Center, built by our Space Development and Test Wing, is a common ground system architecture that is also open, flexible, and scalable to increased demand. Standardization will require dedicated help from industry partners. They must understand that ORS is simply not possible if we continue boxing ourselves into proprietary, stove-piped solutions. Open systems architecture is a must.

In applying "small space" capabilities to ORS requirements, we need to match the level of resources assigned to mission importance. "Small space" is not the answer for everything, and using "small space" for ORS will be inherently risky in the beginning. This needs to be weighed against mission requirements and public perceptions. Many are watching our progress very closely. Overall, we have a great start on developing a lasting ORS capability. Our "small space" infrastructure provides a great foundation, and we are learning a great deal as we go.

For ORS to work, we need to focus on operational capabilities, not single experiments. Going forward, an end-to-end series of ORS capabilities should be factored into the overall space architecture and assigned resources based on mission importance and user needs. Further, we will need to focus on effective mission assurance and proper resourcing during acquisition and operations to ensure we meet ORS needs with minimal risk … not zero risk! ORS has a unique niche to fill in an overall national security space strategy. It is dependent on the right solutions for warfighter requirements in the most efficient manner, whether leasing more commercial communications or fast development of dedicated space missions. Transition to a full ORS capability will require commitment to this revolutionary shift by both government and industry players. Our "small space" efforts helped us reach our dominant position in national security space. The path to ORS we choose today will figure prominently in the US space posture of the future.

Notes:

[1] Arthur K. Cebrowski and John W. Raymond, "Operationally Responsive Space: A New Defense Model," *Parameters*, Summer 2005, 67-77.

[2] Department of Defense, National Security Space Office, "Plan for Operationally Responsive Space," report to Congressional Defense Committees, 17 April 2007

[3] Ibid.

Lt Gen John T. "Tom" Sheridan (BS, Mechanical Engineering, University of Connecticut; MBA, Bryant College, Smithfield, Rhode Island) is the commander of the Space and Missile Systems Center and program executive officer (Space), Air Force Space Command (AFSPC), Los Angeles AFB, California. Lt Gen Sheridan is responsible for managing the research, design, development, acquisition and sustainment of space and missile systems, launch, command and control, and operational satellite systems.

General Sheridan's experience includes acquisition leadership of aircraft, simulator and classified space programs; requirements development across all Air Force space programs; and operational leadership in four different national space programs. He has served as military assistant to the assistant secretary of the Air Force for space, commandant of Air Command and Staff College, director of requirements at Headquarters AFSPC, and most recently as the deputy director of the National Reconnaissance Office.

The Warfighter's Perspective on Space Support

LTG Kevin T. Campbell, USA
Commanding General
USASMDC/ARSTRAT Commander
Joint Functional Component Command
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Huntsville, Alabama

Eight plus years of persistent conflict has taught us important lessons. Chief among these is the fact that for the foreseeable future, our soldiers will consistently be involved in full spectrum operations. We anticipate our Army forces deploying into austere environments where space must play a foundational role. This is especially true in early entry operations. Here, space support is vital. Space enables our ground units to pierce the "fog of war." Space-provided products and services assist our troops in maintaining situational awareness of their position, the position of friendly forces, current terrain information, current and projected weather conditions, and enemy locations and capabilities—all critical requirements when operating in the heart of enemy strongholds.

Freedom of action on today's battlefield is tied to space-based capabilities. Over the course of the last decade, we have made significant advances in providing space-based products and services to our brigades and battalions. Commanders at this level have space support that far exceeds anything available to their peers during Desert Shield and Desert Storm. Our soldiers tell us; however, that products and services (current satellite imagery and communications) delivered from space-based platforms do not consistently reach our lower echelon units—those closest to the fight. Additionally, many of our adversaries understand our dependencies on space and could take action to disrupt our ability to deliver products and services to those engaged in the fight.

If our strategic space systems cannot meet the immediate, real-time needs of our forces in contact, and if potential adversaries are focusing on disrupting our space-delivered services and products, then we must find more effective means of delivering products and services to our front-line units. "Big space" may not be the capability of choice. We may be entering an era where a mix of systems and capabilities is necessary to meet the needs of the warfighter, a time when we must find new ways to ensure information flows to our lower echelon units.

This article discusses why space is important to the soldier, and the capabilities and attributes they need most from space systems. We also describe what US Army Space and Missile Defense Command/Army Forces Strategic Command (USASMDC/ARSTRAT) is doing to explore other means of providing the capabilities and attributes the warfighter needs in order to sustain freedom of action across the battlefield.

When the US Army thinks about space, we tend to think about it from the perspective of our operating concept. Army Field Manual 3-0 describes a doctrine wherein commanders execute offensive, defensive, and stability operations simultaneously throughout the depth of the operational area. We cannot achieve the versatility, agility, lethality, or interoperability required to carry out our doctrine without space capabilities. Space-based systems allow us to operate across larger areas with fewer boots on the ground. Compared to cold war deployment schemes of some 100-square miles, today's brigade combat teams operate within sectors the size of the state of New Jersey. This would not be possible without space support.

In today's environment, our small units must operate independently and semi-autonomously. On today's battlefield, it is at the squad, company, and battalion level where wars are won. Here, timely information enables optimal employment of our small units and enables adequate force protection. At the small unit level, our space-based services and products do not consistently reach the end user—the commander in contact with the enemy.

Our requirements—our warfighter's requirements—are demanding when you consider the need for assuredness, persistence, and responsiveness. We are putting our troops in remote locations on terrain where mountains and valleys separate members of the same combat unit. Under these conditions, terrestrial line-of-sight systems may not give the small unit leaders the situational awareness to operate with relative freedom of action. Any disruption in service exposes our units to greater force protection risks.

If we could bring in the ground commanders, those fighting the fight, and talk about their needs in combat, we doubt if they would be concerned with whether a small or a conventional satellite is used to meet their requirements. We also doubt they would know if a low Earth orbit or a geosynchronous orbit satellite best meets their needs. We do think they would say; they need persistent coverage—they need to talk to small teams deployed in complex terrain, they need information in real time—they need lower resolution data in 30 minutes more than they need higher resolution data in three hours. And, they would also tell us their greatest needs are in the forms of communications and intelligence, surveillance, and reconnaissance (ISR).

So what are the attributes we need in our space systems? Our troops in combat need assuredness, persistence, and responsiveness. Assuredness: confidence we will get the products and services we need. Persistence: there when needed for as long as needed. Responsiveness: the ability to task an asset in real-time for rapid delivery of information to the troops in contact. These attributes would seem inherent in our space systems. However, our architectures, concepts, and perhaps culture interfere with the delivery of products and services from our space-based platforms to the lower echelons.

There are many reasons why products and services may not be delivered to the small unit in a timely manner. We recognize that our space assets are strategic in nature. They were designed and fielded to meet the strategic needs of the nation. We are, in effect, attempting to fulfill tactical needs with systems designed to meet strategic requirements. We carefully guard the capabilities and sometimes even the existence of our strategic satellites. Products produced by them are normally classified at a level that may place them out of reach of the commanders at the small unit level.

We are not advocating a focus on lower echelons at the expense of other users. Our national space assets have been put in place to meet the strategic needs of our nation. We think it is absolutely critical that we continue to field and operate these very capable space systems. But, we know we cannot do it all with large spacecraft, and we know that "big space" is challenged meeting all of our national and strategic requirements.[1] We need augmenting systems to meet our warfighting requirements.

We have leveraged our strategic space systems to meet tactical level requirements over the years. Arguably, we have enjoyed success. However, today's combat environment introduces more demanding tactical level requirements on our strategic systems. The changes in the operating environment have caused us to search for other viable means of providing persistent, responsive ISR and communications to the solider at the tip of the spear.

Today, many of the soldier's communications and ISR needs are being filled by unmanned aerial vehicles (UAV). Looking at the predator alone, we have more than 30 combat air patrols operating 24 hours a day, seven days a week, nearly 52 weeks a year. We passed 250,000 flying hours with the predator after 12 years of operation in June 2007. In the next 20 months we added an additional 250,000 hours of operation. In the past seven months, an additional 100,000 hours were flown.[2]

To meet the warfighter's need for assured, persistent, and responsive communications for the lower echelons, the US Army began deploying communications relay payloads on the Shadow 200 UAV in 2007. Flying around 14,000 feet above sea level, the Communication Relay Package-Light system has demonstrated the ability to extend the range of tactical communications to around 170 km—far beyond the line-of-sight range of very high frequency or ultrahigh frequency radios. The Shadow is currently being operated in a similar role supporting the Marine Amphibious Brigade in Helmand, Afghanistan.[3] Here, the use of a UAV to provide airborne relay "can effectively connect to units operating in mountainous area, where terrestrial radio communications are typically masked and screened by the terrain."[4]

Do UAVs provide assured capabilities? Are UAVs responsive? Are they persistent? We think if you ask a ground commander you will get a resounding "yes" to each of these questions. Because of these attributes, the numbers of and uses for UAVs continues to grow. This is, in part, because traditional space systems cannot meet all the warfighter's needs for persistent and responsive ISR and battlefield communications.

USSTRATCOM's Operationally Responsive Space (ORS) Concept of Operations, 28 December 2009, states that "the primary purpose of the ORS initiative is to prepare the elements required to implement responsively-provided space capabilities, and to execute the delivery of such capabilities in response to the expressed joint force commander need." ORS holds promise for the future, and we look forward to the fielding of tactically responsive space systems in a timely manner. TACSAT-3 is a giant step in the right direction. ORS-1 appears to be following in a timely and cost effective manner as well.

At USASMDC/ARSTRAT, we are currently evaluating two small satellite prototypes designed to meet the warfighter's persistent and responsive ISR requirements. Working with the ORS Office, USASMDC/ARSTRAT built eight small satellites to augment communications systems. Our objective in building these satellites was to examine alternative methods of providing support to the ground commander. The launch and test of the first of these small satellites is scheduled for the first half of 2010. The remaining seven will follow shortly thereafter.

USASMDC/ARSTRAT is also working with the Office of the Secretary of Defense ISR task force, as well as with the Army, to develop airships. There is a demand in the theater for a payload and platform that provides persistence and responsiveness to the units in contact. The warfighter needs a system capable of loitering and staring into a sector for extended periods. For example, commanders need platforms equipped with moving target indicator phenomenology, or other situational awareness payloads, capable of providing immediate information to the troops on the ground and responsive to real-time tasking. The commander on the ground wants persistence and responsiveness; airships may be capable of delivering it.

At USASMDC/ARSTRAT, we are continually looking for new ways to support the warfighter. To meet their needs, we are evaluating small satellites, hybrid airships, and high altitude systems. As we look across the universe of potential capabilities, whether it is space, high altitude, air, or ground, we strive to find faster and more cost-effective ways and means to deliver support to the lower echelons. Our perspective remains clear. It is a bottom up look, not a top down look, and we have to remain resolute in our willingness to explore alternatives that best support the small unit conducting the close-in fight. Secure the high ground!

Notes:

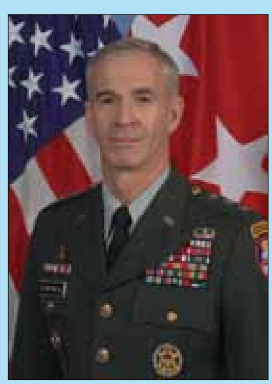
[1] US Army Transportation Research and Development Command Pamphlet 525-7-4, *The US Army's Concept Capability Plan*, Space Operations 2015-2024, version 1.0, 15 November 2006.

[2] AFNS, "Predator passes 600,000 flight hours," 30 September 2009,

[3] "Airborne Communications Relay Could Become Primary Mission for Tactical UAVs," *Defense Update*, 11 January 2010, http://defense-update.com/features/2010/january/airborne_relays_for_uavs_110110.html.

[4] Ibid.

Mr. Cecil Longino contributed to the development of this article.



LTG Kevin T. Campbell (BS, Worcester State College, Worcester, Massachusetts; MS, Personnel Management, University of New Hampshire) is the commanding general, US Army Space and Missile Defense Command/Army Forces Strategic Command, and serves as the commander for the Integrated Missile Defense Joint Functional Component Command (JFCC-IMD). This component is responsible for meeting USSTRATCOM's (United States Strategic Command) Unified Command Plan responsibilities for planning, integrating, and coordinating global missile defense operations and support. JFCC-IMD conducts the day-to-day operations of assigned forces and coordinates activities with associated combatant commands, other STRATCOM Joint Functional Components and the efforts of the Missile Defense Agency.

Operationally Responsive Space: Not New, **Just Bringing New Approaches to Space**

Dr. Peter M. Wegner
Director, Operationally Responsive Space Office
Kirtland AFB, New Mexico

Moving Past the Why to the How

One question that is asked with less frequency these days is, "why operationally responsive space (ORS)?" Today there is a broad understanding of the reasons why ORS capabilities are needed. The Quadrennial Defense Review (QDR) Report released on February 2010 noted, "Future adversaries will likely possess sophisticated capabilities designed to contest or deny command of the air, sea, **space**, and cyberspace domains."[1] Furthermore, the QDR highlights that, "…fielding capabilities for rapid augmentation and reconstitution of space capabilities will enhance the overall resiliency of space architectures."[2] The report goes on to say that in the future America's adversaries will rapidly develop new tactics, techniques, and procedures utilizing the latest commercially available technologies. In response the QDR states, "The department must not only prepare for those threats we can anticipate, but also build the agile, adaptive, and innovative structures capable of quickly identifying emerging gaps and adjusting program and budgetary priorities to rapidly field capabilities that will mitigate those gaps."[3] Finally, the QDR notes the sea-state change required in managing the acquisition of complex weapon systems to solve the challenges. Specifically, "The department and the nation can no longer afford the quixotic pursuit of high-tech perfection that incurs unacceptable cost and risk."[4] The changing nature of the national security posture articulated by the QDR provides clear justification for pursuit of ORS. A broad understanding of these key challenges facing the nation has moved the question beyond "why ORS?" into "how ORS"?

Fundamentals of ORS

Before we delve into the question of how to create an ORS capability, we should reflect on what exactly is ORS? Thankfully the ORS Office was chartered with strong policy and guidance. For example, the Department of Defense (DoD) definition of ORS as specified in a deputy secretary of defense memorandum is "assured space power focused on timely satisfaction of joint force commanders' (JFC) needs,"[5] Understanding the elements of the definition is the key to differentiating the fundamental nature of ORS from traditional approaches.

- *Assured:* Sufficiently robust, timely, agile, adaptive, and resilient to achieve desired outcomes with a high degree of certainty.
- *Space power:* The total strength of the nation's capabilities to conduct and influence activities to, in, through, and from space to reach its objectives.
- *Timely satisfaction:* Address needs and deliver solutions within operationally relevant timelines.
- *JFCs' needs:* Establish, expand, and secure operational reach; acquire, refine, and share operational knowledge; identify, create, and exploit effects to create the desired operational outcomes; and link tactical forces to strategic objectives.

The US Strategic Command's (USSTRATCOM) ORS concept of operations provides further detail by outlining a three-tiered set of solutions to future responsive space needs.[6] These tiers can be explained in terms of both operational readiness and notional timelines. The Tier 1 solution calls for employing existing space capabilities in minutes to hours. Tier 2 solution set calls for the ability to rapidly deploy "on-call, ready-to-field" assets in days to weeks, and finally Tier 3 solutions will enable the development of new capabilities in months (not years).

Implementing ORS

Implementing ORS necessarily involves accepting a complementary approach to delivering space capabilities. The question of how best to implement ORS hinges on key principles that define capabilities that are "good enough to win." The ORS Office is taking a systematic approach that builds upon on the lessons learned from previous rapid innovation programs and applies those to the principles outlined below.

1. **Get to know your customer.** A necessary step in developing the ORS response capability is to understand the customer and precisely identify their most critical needs. Narrowing the solution set is an imperative. It is impractical to provide a continuum of solutions to a continuum of potential needs. The ORS mission statement clearly identifies JFCs as the customers. Therefore, before building a capability that is "good enough," one must thoroughly understand what "good enough" means. The ORS Office is achieving this analytically by executing a capabilities based assessment (CBA) in parternship with Air Force

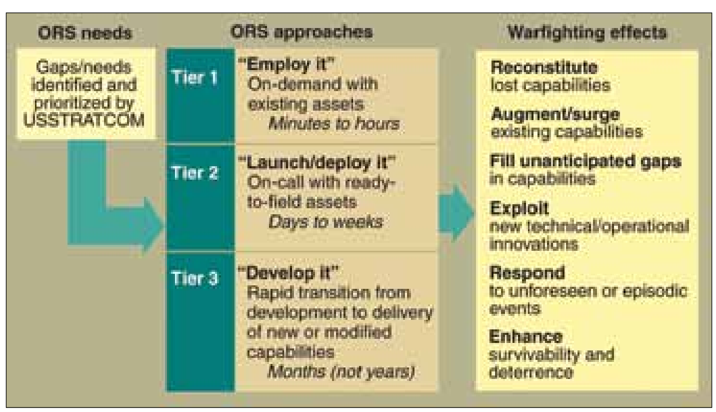


Figure 1. ORS three-tiered solution architecture.

Space Command (AFSPC) and USSTRATCOM. This is also being achieved through direct outreach to combatant commanders (CCDR). The ORS Office Tier 1 Division is actively engaging in exercises and war games with the combatant commands to develop tactics, techniques, and procedures to rapidly employ existing space capabilities. This interaction has had the practical effect of limiting the range of solutions to focus on the most necessary needs. Doing so results in delivery of tailored capabilities to support the most pressing needs for the customer.

2. **Adapt over innovate; innovate out of necessity.** The ORS Office often says, "ORS is not new, it's just bringing new approaches to space." The ORS Office is adapting concepts and principles that have a proven history of success in commercial and military as well as international and domestic for both space and non-space applications. At the core is ORS's adaption of a standards-based modular open systems architecture approach. Unmanned Aerial System (UAS) Flight Plan 2009-2047 explains that "Compliance with common data formats and interface standards is key to achieving modularity and enabling remotely piloted aircraft (RPA) and unmanned aerial vehicle (UAV) versatility."[7] Similarly, the ORS Office believes it is key to achieving the kind of flexibility that will enable us to respond to the full array of anticipated JFCs' needs on a timeline that preserves their assured access to space. As a result, we will pattern our training programs, logistics systems, and other supporting functions after these successful responsive capabilities.

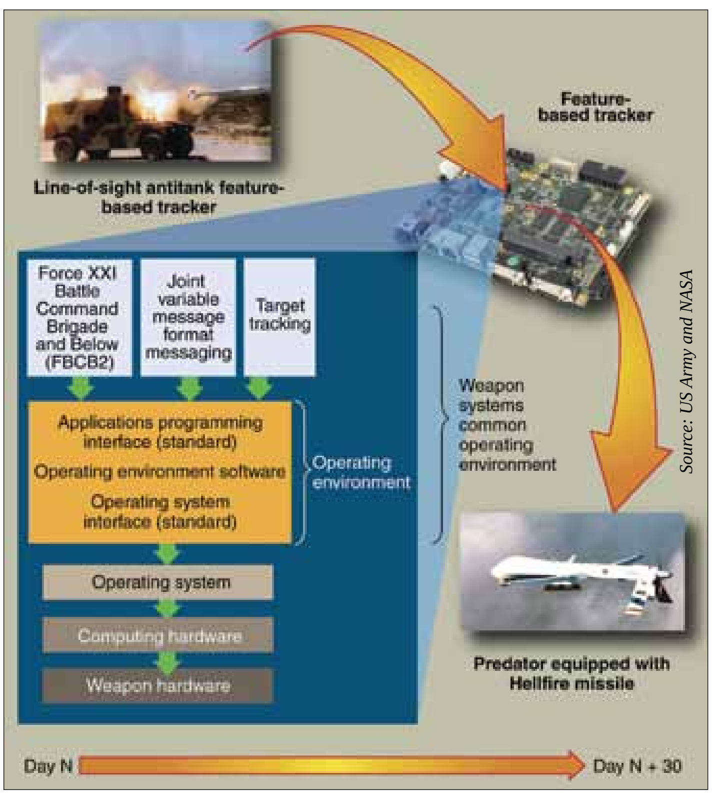


Figure 2. The Predator UAS was outfitted with a Hellfire missile in just over 30 days through the use of a modular open systems architecture.[8]

3. **Apply external constraints.** Guidance provided to the ORS Office at its inception clearly and purposefully imposed unprecedented cost and schedule goals to drive the family of solutions they considered appropriate and sustainable for ORS. The 2007 National Defense Authorization Act highlights that launch vehicles should be less than $20 million a copy and integrated satellites should be less than $40 million a copy. [9]

   To enable solutions in this cost class it is critical to adopt a risk posture appropriate for the cost and lifetime of the system. It is often said that customers want Class A performance and reliability on a Class D budget and schedule. ORS plans to build systems that provide affordable, "good-enough-to-win" capability to our customers with a mission life of 12 to 18 months. Therefore, reliability goals are set at 80 percent, that is, four out of five ORS spacecraft should be fulfilling their mission one year out after launch. A reliability requirement this low is as foreign to the space community as $40 million spacecraft. However, the RPA community has set a precedent by establishing operational requirements that tolerate higher failure rates than manned systems. The US Air Force RPA and UAV strategic vision points out that "accident rates for the Predator and Global Hawk are each an order of magnitude greater than the accident rate for Air Force manned aircraft, but they are below the rates established in the operational requirements documents for those systems."[10]

4. **Develop through missions.** Another principle of the process to develop the ORS response is the use of end-to-end missions to give context to innovations and guard against concepts and technologies that seem effective in isolation, but can't be implemented collectively into a response capability. We have defined a series of "enabler" missions that will incrementally outfit the ORS end-state architecture with the full suite of tools needed to transition an operational ORS response capability to the services. This is one key to overcoming the problem identified by the General Accounting Office in October of 2009 that, "satellites, ground control systems, and user terminals in most of DoD's major space system acquisitions are not optimally aligned, leading to underutilized satellites and limited capability provided to the warfighter."[11]

5. **Collaborate.** The ORS Office is structured as a lean organization and recognizes the need for collaboration to achieve success. Because of advancing technology and increased access to space an increasing number of actors can lend expertise to the ORS effort. Today the ORS Office is investing with key partners to architect and demonstrate the critical enabling elements for an ORS capability. The ORS Office is leveraging expertise and investments from across the space enterprise. This includes investments by the Air Force Research Laboratory to develop a plug and play spacecraft architecture, the Office of Naval Research for the development of low-cost, agile payloads, and the Army Space and Missile Defense Command's investments

in very-small, low-cost nanosatellites. Collaboration is ongoing with National Aeronautics and Space Administration, Defense Advanced Research Projects Agency, and combat support agencies, as well as commercial industry for innovative approaches to responsive launch and range, modular spacecraft systems, and agile ground system architectures for rapid tasking, processing, exploitation, and dissemination of products to the warfighter.

Addressing the Timeline Challenge

In applying the aforementioned key principles, the ORS Office is still faced with the key question, "How can capabilities be developed and delivered under operationally relevant timelines?" To answer this question, the ORS Office analyzed the key lead time drivers for an ORS solution. In 2008, the Naval Research Laboratory determined that the key lead time driver for ORS was the availability of critical spacecraft and launch vehicle components. The timelines from order to delivery of these capabilities ranges from one to 24 months. The Air Force Research Laboratory has demonstrated that once these components are on hand they can be configured into a plug and play architecture that enables a spacecraft to be rapidly assembled and tested in a matter of hours. The ORS Office in partnership with the Space-X Corporation demonstrated in 2008 that, once a spacecraft was completed, it was possible to go from cold storage to launch in less than six days. The last piece of the puzzle, rapid on-orbit checkout, has been demonstrated in both commercial satellite programs and in the TacSat-3 mission where the spacecraft was checked out and delivering products in a matter of days. Therefore, one of the challenges for ORS is to manage the inventory of these critical components and develop a plug and play architecture that will enable them to be rapidly assembled, launched, checked-out, and operated in days to weeks.

The ORS Office studied existing models to arrive at a solution to this problem. Models were found in two operational capabilities that are currently fielded in support of the JFCs: UASs and the U-2. After 55 years, the U-2 has evolved into a fully modular architecture that allows the aircraft to carry a variety of sensor systems in either the nose, in superpods under the wings, or attached to the upper fuselage. Today's existing architecture accommodates modular payloads to perform day, night, and all weather reconnaissance, electronic support, and communications relay missions. The USAF RPA and UAV Strategic Vision states, "Modularity is an alternative to equipping a single airframe with every capability. Modular payload bays, reconfigurable airframes and attachment points, and responsive flight control software that conform to common standards can allow for rapid re-tasking of vehicles at any time."[13]

The ORS Blueprint

The ORS Office developed a blueprint for implementing ORS by incorporating features similar to those of these successful models. In space terms the U-2 aircraft platform becomes the spacecraft bus and launch vehicle that carries the necessary payloads. The airfield is analogous to the launch complex and ranges while the mission control center is analogous to the spacecraft operations center. The tasking and data dissemination systems in many cases share the same features. A significant missing part is the wing maintenance function and the operators who are trained to perform the mission. The ORS Office blueprint pulls these components together around an organizing constructed referred to as the Rapid Response Space Works (RRSW). This capability, nicknamed Chileworks, is a nod to the ORS Office location in New Mexico where green chilies are the culinary focus. The RRSW includes several key components: a "design cell" that develops concepts/solutions in response to JFCs' needs; a series of mission kits that provide payload capability; standard spacecraft bus platforms on which the mission kits are integrated; a rapid assembly, integration, and test capability; a rapid integration and launch function; and a ground infrastructure that ensures rapid tasking and deliver of products to the warfighter.

The Way Ahead

Remain focused on the mission.

The focus of the ORS Office remains on obtaining a very clear appreciation of the specific needs of the JFCs. If the possibility of a promising ORS solution exists, its viability is in how effectively those delivered capabilities can be brought to bear as part of a total effort. Because circumstances are often unique to a specific JFC, ORS emphasizes the value of tailored capabilities. The office has laid out a series of enabler missions that will integrate these elements into a synchronized, end-to-end demonstration of capabilities. In the execution of ORS enabler missions, the ORS Office is continuing to engage with warfighters to conduct a joint military utility assessment (JMUA) of these capabilities and to explore the tactics, techniques, and procedures to employ future ORS capabilities. The lessons learned from these JMUAs will feed back into the development of the critical ORS enablers.

	Lead time in months		
Structures	Best	Nominal	Worst
Primary Bus Structure	5	6	7
SV to LV adapter	6	7	14
ACS			
Star Tracker	9	12	24
Gyroscope	12	14	18
Reaction wheel	12	14	24
Torquerod	8	12	15
Magnetometer	8	12	15
Coarse Sun Sensor	8	10	12
GPS Receiver (if part of ACS)	2	14	20
Antenna Positioning Mechanism	15	18	24
Solar Array Gimbal	15	18	24
Comm			
S-band Transponder	12	14	16
S-band encryption / decryption	10	12	14
S-band antenna	7	8	10
High rate encryptor	12	14	16
K-band high gain antenna	16	18	20
K-band transmitter	12	14	16
Propulsion			
Prop tank	9	15	22
Thrusters	6	9	12
Propulsion system	12	20	30

	Lead time in months		
EPS	Best	Nominal	Worst
Solar Arrays	16	18	24
Battery	16	18	20
PDU	8	10	12
CCU	8	10	12
PCU	8	10	12
C&DH			
Bus Processor board	6	12	14
NVM board	6	12	14
PDE board	6	12	14
GDE board	6	12	14
PACI board	6	12	14
GPIO board	6	12	14
Thermal			
Heaters	2	3	5
MLI blankets	0.5	1.5	3
Thermal sensors	1	4	6
FOSR	1	3	6
OSR tiles	1	3	6
Thermostats	0.5	4	6
Heat pipes	3	4	5
Space rated electronic components			
Chips, FPGAs, ASICs	3	4.5	6

Source: ISET Bus Standards Working Group, 2008

Figure 3. Key Lead Times for critical spacecraft components.[12]

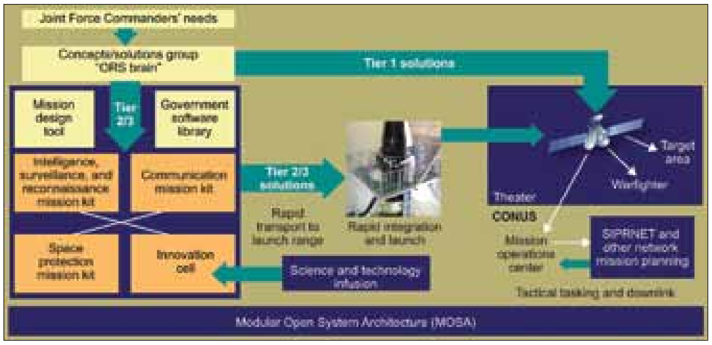


Figure 4. The ORS 2015 Blueprint encompasses components necessary to enable rapid delivery of solutions to JFCs' needs.

Stay true to the principles.

The five principles outlined above help to define the ORS approach to achieve "good enough to win" capability. Staying true to those principles will help ORS remain on track to deliver an agile, flexible, and complementary architecture that addresses emerging and disruptive threats in operationally relevant timelines. We are taking several actions well in advance of our 2015 deadline to avoid critical pitfalls. First, despite the fact that Congress exempted ORS from the Joint Capabilities Integration Development System process, at the request of the commander of USSTRATCOM we are conducting a CBA in partnership with AFSPC and the combatant. This CBA will result in a validated requirement for ORS capabilities. Cost estimating tools are also being developed (backed up by existing small satellite programs) to estimate the annual cost to stand up and sustain the ORS response capability through 2020.

Deliver capabilities that can be successfully transitioned.

The ORS Office fully recognizes that it is only chartered to architect and demonstrate ORS capabilities. Success in attaining the ability to organize, train, and equip using these capabilities depends upon a seamless interface with the services' mandate to conduct operations. As noted in the USAF UAS program, transitions have traditionally been a challenge for new capabilities that grew out of a need to augment or modify an existing and established paradigm.[14] The ORS Office is working to encourage institutional buy-in with proactive engagement throughout the space community. Ultimately, success is gauged by the ability to deliver synchronized and integrated capabilities to achieve effect desired by the JFC.

Conclusion

The challenges to building an ORS capability are many and the risks are significant. Some still question the utility of small, single-mission focused satellites and many doubt the feasibility of rapid call-up to launch of operational systems. But, there is growing evidence from international space programs and the service laboratory's TacSat programs that there is clear military utility in small, low-cost satellites. The ORS Office is patiently moving aside the technical challenges to enable call-up to launch in days. Building this capability will require focus, patience and dedication. It was 23 years between the U-2 proposal and its eventual implementation in a wing construct. A truly modular Wing implementation did not come until 10 to 15 years later. Building an ORS capability will require staying the course through a "crawl, walk, run" development process. If that is maintained, the warfigher, and the nation will be the clear beneficiaries.

Notes:

1 2010 Quadrennial Defense Review Report, February 2010, http://www.defense.gov/qdr.

2 Ibid.

3 Ibid.

4 Ibid.

5 "DoD Operationally Responsive Space Memorandum," deputy secretary of defense memorandum, 9 July 2007.

6 US Strategic Command Concept of Operations for Operationally Responsive Space, 28 December 2009.

7 "US Air Force Unmanned Aircraft Systems Flight Plan 2009-2047," Headquarters US Air Force, Washington DC, 18 May 2009.

8 Department of Defense Open Systems Joint Task Force, February 2009, http://www.acq.osd.mil/osjtf/mission.html.

9 Public Law 109-364, 17 October 2007.

10 "The USAF Remotely Piloted Aircraft and Unmanned Aerial Vehicle Strategic Vision," Headquarters United States Air Force, Washington DC, 2005.

11 "Defense Acquisitions: Challenges in Aligning Space System Components," GAO-10-55, 29 October 2009.

12 Dr. Kirk Stewart, "Long Lead Items, Categorization, and Solution Approaches," report to the Integrated Systems Engineering Team, Naval Research Laboratory, 25 October 2007.

13 "The USAF Remotely Piloted Aircraft and Unmanned."

14 "US Air Force Unmanned Aircraft Systems Flight Plan 2009-2047."

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Prior to this position Dr. Wegner served as the technical advisor to Air Force Space Command, Directorate of Requirements. In this position Dr. Wegner helped guide development of Air Force future space concepts based on science discovery and technology trends. Dr. Wegner was responsible for ensuring the alignment of the Air Force's space science and technology portfolio with the Air Force's future capability requirements.

Dr. Wegner also served as a senior aerospace engineer with the Air Force Research Laboratory (AFRL), Space Vehicles Directorate. He developed AFRL's Operationally Responsive Space Program; overseeing the development of technologies for responsive spacecraft and launch vehicles. Dr. Wegner also led the DoD TacSat Joint Experiments integrated planning team. Dr. Wegner also served as the branch chief for AFRL's Spacecraft Component Technology Branch. This AFRL center of excellence conducted science and technology research in space and launch vehicle systems; including spacecraft power systems, structures, mechanisms, and dynamics and control.

Senior Leader Perspective

Operationally Responsive Space: An Avenue to **Evolving the Space Enterprise Architecture**

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Pentagon, Washington DC

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National Security Space Office
Pentagon, Washington DC

For the space community as a whole, the fundamental nature of operationally responsive space (ORS) is one of change. The 9 July 2007 deputy secretary of defense memorandum on ORS acknowledged this in prescribing the definition of ORS and in declaring, "The need to adapt space capabilities to changing national security requirements provides the incentive for innovation through ORS."[1] This comprehensive vision of change with its implications for enhanced operational utility is a centerpiece of ORS. Further emphasizing the need to adapt, the deputy secretary of defense memorandum concludes, "Attaining more agile, resilient, and tailorable capabilities requires a new way of thinking that emphasizes flexibility across the spectrum of doctrine, organization, training, materiel, leadership and education, personnel, and facilities—ORS provides this conceptual framework."[2]

The mention of conceptual frameworks appropriately invokes the notion of system architectures. While there are many definitions of system architectures, more generally referred to here as architectures, most emphasize that an architecture is a formal description of a system presented in an organized way.[3] An architecture "defines the system components or building blocks and provides a plan from which products can be procured, and systems developed, that will work together to implement the overall system."[4] Importantly, architectures allow an organization to manage their investments in order to meet their business needs.[5] Primarily for the Department of Defense (DoD), these investments address the warfighter's needs. With the complexity of our space systems and their increasing integration across the spectrum of joint operations, the value of architecting is all the more important in determining how to invest for maximum effect. Our space systems have served this nation exceedingly well, but the framework must continually adapt to an ever-changing global environment and a variety of new domestic realities.

A major challenge for ORS is to effectively integrate into the existing architecture of national security space systems in a way that enhances overall capability. This integration has to be done in a way that will efficiently and effectively add value while preserving the essential contributions of existing systems and yet illuminate a way ahead in select segments of the overall architecture. This approach amounts to evolving the architecture. The outcome results in better optimizing existing systems and adding new specialties in order to leverage the best of the capabilities uniquely suited to each. A well-developed architecture helps to depict the seams between what exists today and what might exist tomorrow by creating a common backdrop for understanding. In the case of ORS, the value is as much in changing culture, and hence in redefining certain elements of the overall architecture, as it is about developing a single end product. In the long-term, many of the principles proven under operationally responsive space efforts may be adapted by the larger space enterprise or spur innovation outside of what initially might be considered unique to ORS. The larger space enterprise includes elements of the DoD and the intelligence community as well as other US civil capabilities, and even includes allied and commercial needs and capabilities that are essential to unified action when operating in a coalition environment.

The basis for contributions by ORS to evolving the overall architecture is multifaceted. Foremost, it is based upon the application of joint doctrine to the evolving threats posed by adaptive adversaries and the growing complexity of relations with global partners and regional actors alike. The operational concepts and premises by which ORS reflects joint warfighting tenants is an evolution of space doctrine on a scale matching the changing nature of the joint operational environment itself. This is especially true as commanders pursue integration of efforts under the broader concept of unified action. Consequently, the merits of ORS are distinctly different from those of legacy space systems. ORS supports the joint force commander (JFC) under a business model that provides capabilities judged as "good enough" rather than exquisite. This being the case, benefits to the overall space architecture come from the complementary nature of both types of capabilities and the recognition that balance between the two achieves a degree of resilience unachievable under a single approach.

A clear definition of terms is essential to codify ORS as an element of the evolving space architecture. For DoD, the meaning of ORS has been defined by a deputy secretary of defense memorandum as "assured space power focused on timely satisfaction of joint force commanders' needs."[6] The key elements of this definition have their basis in joint doctrine and help define how ORS may play into the broader space architecture. It is useful to expand upon this notion to better understand the doctrinal linkage between the role of the JFC and foundational aspects of ORS. Along with a clear definition, underpinning the ORS initiative with doctrinal ties strengthens the whole conceptual basis for evolving the overall space architecture.

ORS establishes clear expectations by focusing on the needs of JFC. To achieve the degree of success expressed in the definition requires a doctrinal understanding of the role of combatant commanders (CCDR) and the JFCs, and the expectations set forth in executing campaigns according to joint doctrine. It is CCDRs that design campaigns and with their JFCs both plan and execute those campaigns by applying operational art.[7] Stating that ORS is focused on the JFC translates to affirming that ORS is focused at the level where the JFC exercises operational art. The focus of these commanders is the integration of capabilities to "generate decisive joint combat power."[8] As such, JFCs are responsible for unified actions by achieving synergy with military forces of other nations as well as nonmilitary and nongovernmental organizations and agencies.[9]

Features of ORS help evolve the space architecture by reinforcing this objective of coordinated action as a recurring theme in joint doctrine. The JFC seeks a high degree of integration and synchronization in directing both joint operations and unified action. The concept of unified action is called out as the broader of the two terms and "highlights the synergistic application of all the instruments of national and multinational power and includes the actions of nonmilitary organizations, as well as military forces."[10] In practice, the term, joint operations, increasingly is viewed as almost synonymous with unified action. As stated in Joint Publication 3-0, "in common parlance, joint operations has increasingly this connotation."[11] Coincidentally, the larger space enterprise draws upon all the same actors as those defined under unified action.

ORS offers the potential to dramatically enhance unified action through its reduced barriers to entry into the space sector for potential actors. Attributes of ORS provide a unique opportunity for contributors to lend space capabilities in a coalition fashion that supports unified action. As an example, coalition efforts might be presented as a constellation of small, special-mission satellites through shared investment and mutual benefit. Such an arrangement with appropriate protocols in place also raises the notion of an added deterrence value derived from mutual interests in space platforms shared among several nations. Additionally, commercial entities may also contribute in a variety of ways to joint operations and unified action during both campaigns and military operations other than war in coordination with the CCDR and subordinate JFCs.

Since military operations depend upon the synchronization and integration of necessary capabilities from all domains, ORS seeks to achieve the means for highly integrated space capabilities. As a means to this end, ORS is patterned to take on the qualities that are objective characteristics of the very joint force with which ORS seeks to integrate. Therefore, ORS seeks to adopt key characteristics of the future joint force, namely to be interoperable, expeditionary, tailorable, fast, resilient, and agile. Characteristics such as these "will guide how the joint force is developed, organized, trained and equipped."[12] The challenge for ORS is to balance the need for these qualities with the realistic application of refined capabilities in a coalition environment. Achieving the right balance between protecting sensitive means and providing assured space power may mean designing to and delivering capabilities that are state-of-the-world rather than state-of-the-art. Success will be in the calculus of evaluating the relative importance of each key characteristic and then determining "good enough." No doubt that this is a tall order for ORS and one that is unachievable without the enabling infrastructure in place to be able to execute.

The characteristics of the future joint force and the ensuing demand upon ORS has ramifications in the way of the infrastructure required to implement this well-placed emphasis on JFCs. A derivative of the need for agile and adaptive space capabilities is a similarly responsive space infrastructure. Launch, range, and command and control capabilities are just a few among the areas requiring attention. Traceability to the needs of the JFC helps frame the end goal but is not alone sufficient. For example, the means to streamlined acquisition, reduced production costs, and efficiency in schedule are all highly desirable as objectives to deliver capability more readily. The maturity of technology, ability to accurately portray requirements, and availability of funding limit the degree to which the entire space infrastructure can flex to accommodate an evolving architecture. For ORS, though, recognizing a narrow subset of the warfighter's need and working toward this end offers an advantage. Once more refined warfighter requirements are accepted, secondary concerns become more likely candidates for tradeoffs in decision making. The manifestation of these tradeoff decisions is an ORS strategy that provides a solution to meet that need by delivering "good enough" capability.

Achieving "good enough" capabilities means sufficiently understanding the needs of the end user. "Good enough" is surely not to be interpreted simply as intentionally degrading a system's capability, but rather discerning the requirement sufficiently well to satisfy the need at an acceptable level of performance to provide utility. Beyond documentation of requirements, an ongoing, frank dialogue with the end user is essential to ORS succeeding. Reaching an understanding of what is most important to the warfighter opens the trade-space for arriving at what is "good enough." Often this discussion involves exploring the comfort level or degree of pain an operator is willing to endure to obtain needed capability. This back and forth between customer and supplier distills the true requirements from the broad need. Doing so establishes a solid requirements foundation upon which to resist any tendency towards requirements creep. The tradeoff decisions that ensue from the dialogue also imply a willingness to accept risk beyond what traditionally might be the case. This is, in part, because the risk equation is structured to be fundamentally different from the outset.

ORS approaches risk from the advantage of being a subset of the larger space architecture. In general, ORS can tolerate a higher level of risk. Legacy space systems have evolved to the point of providing exquisite capability and the nation has invested huge sums to ensure robustness, survivability, redundancy and a pipeline of follow-on systems. Consequently, in routine cases, ORS can approach risk differently by relying on the overwhelming suite of core capabilities being provided, and subsequently the majority of risk being shouldered, by traditionally exquisite space systems. ORS can then operate in a niche market to provide tailored capabilities on the margin or dedicated capabilities to disadvantaged users. With reassurance afforded by the exquisite portion of the space architecture, ORS has the flexibility to take the more tailored approach of "good enough." Under such ground rules, tradeoff decisions involving cost, schedule, and performance may inherently assume more risk. This may mean opting for single string designs verses redundant strings, or state-of-the-world verses state-of-the-art capabilities, or even streamlined testing to meet cost and schedule objectives. Gains are achieved by tolerating increased risk that, in effect, has been paid for by the larger part of the existing space architecture. However, this state of affairs between exquisite and "good enough" is potentially upset when there exists the need for augmentation or reconstitution.

In providing the ability for augmentation or reconstitution, ORS offers a means to assure that space capabilities remain available in times of crisis. Loss of space capability, whether caused by a gap in coverage due to an unforeseen event or hostile intent, demands an ability to augment the existing systems or reconstitute a minimum level of capability. The larger space enterprise may have to rely upon ORS to achieve the timeliness required for augmentation or reconstitution. Other than those systems already in place, the existing space architecture offers few alternatives to rapidly deploy additional space capability. When primary, exquisite systems are held "at risk," the need to weigh the risk of not having the ability to augment or reconstitute comes into play. Besides organic ORS options to rapidly deploy, likely alternatives for augmentation or reconstitution can result from contributions due to coalition arrangements. Evolving the complete architecture means drawing a distinction between the types of operating environments, for instance contested verses benign, and adjusting to the nuances of the various scenarios that put space systems at risk. Just as ORS has dependencies on the bulk of the space enterprise for its routine execution, under certain conditions the attributes of ORS can provide assurance that the space enterprise architecture as a whole has the resiliency to respond in crisis, as well as during steady state conditions.

Conclusion

In the end, success for ORS will be measured not only by how it supports JFCs but by how well it fits into the overall space enterprise architecture. A well-constructed architecture helps to manage the complexity of the enterprise and maintain focus on desired outcomes. The suite of capabilities that ORS offers and the manner in which ORS reflects the tenants of joint doctrine can fundamentally change today's space architecture in a positive way by bringing added capability to the joint force. The synergy between ORS and legacy space systems can liberate each segment to optimize capabilities according to their unique strengths. The emphasis on the "good enough" business case and an inherently more tolerant risk equation provide a degree of freedom in tradeoffs between cost, schedule, and performance. Certainly, ORS offers a viable alternative to sustaining space capabilities through augmentation and limited reconstitution. The potential for shared deterrence is also possible by using a coalition approach to fielding space capabilities. Contributions by ORS provide a means to evolving the space architecture and, in doing so, both reinforce the substantial contribution of space capabilities to the joint force and provide assurance of existing capabilities. Notably, evolving the architecture by embracing ORS requires a shared resource commitment or the architecture is hollow. Beyond resources, it requires a boldness to accept change and step out in a new direction in order to maintain this nation's edge in space and, ultimately, advance joint capability in all domains.

Notes:

[1] US, Deputy Secretary of Defense, Department of Defense, Operationally Responsive Space, memorandum, 9 July 2007.

[2] Ibid.

[3] Wikipedia, "Systems architecture," 23 November 2009, http://en.wikipedia.org/wiki/Systems_architecture.

[4] Ibid.

[5] Ibid.

[6] Operationally Responsive Space, memorandum.

[7] Joint Publication 3-0: Joint Operations, 17 Sep 2006 with Chg 1, 13 Feb 2008: III-4.

[8] JP 3-0, II-4

[9] JP 3-0, II-3

[10] JP 3-0, II-3

[11] JP 3-0, Figure II-2

[12] United States, *Capstone Concept for Joint Operations*, version 2.0, August 2005, 20-21. (Note: version 2.0 has been updated by version 3.0 yet authors' views are that the specific reference cited remains valid to joint operations.)

Mr. Joseph D. Rouge (BS, Aerospace Engineering, University of Southern California; MS, Aerospace Engineering, University of Southern California; MS, Business Administration, Auburn University) is the director, National Security Space Office (NSSO), the Pentagon, Washington, DC. He is responsible for leading a multi-agency unit tasked to create unity of effort across all of National Security Space. Specifically, the NSSO is responsible for promoting synergy and integrating interagency space policy, strategy, acquisition, launch, planning programming, and technology development.

Mr. Rouge came on active duty in September 1974, serving in a variety of positions involving space surveillance systems, Strategic Defense Initiative Programs, and systems engineering and program integration. He has served on the faculty of the Industrial College of the Armed Forces, at the Air Force Inspection Agency and on the staff at Headquarters US Air Force.

Mr. Rouge was a research fellow at the Airpower Research Institute, located at Air University's Center for Aerospace Doctrine and Education, where he authored a book on national military space strategy. He was also a research fellow at the Industrial College of the Armed Forces, authoring a book on national security strategy. Mr. Rouge retired from active duty as chief of NSSO's Integration Division, and he served as associate director before assuming his current duties as director.

Mr. John Puffenbarger (BS, Electrical Engineering, US Air Force Academy; MS, Space Operations, Air Force Institute of Technology) is a senior systems engineer for TASC, Inc. supporting the National Security Space Office. After commissioning in 1978, he completed Undergraduate Pilot Training at Columbus AFB, Mississippi and then served tours at Charleston AFB, South Carolina as a C-141 instructor pilot and flight examiner in airland, formation airdrop and aerial refueling missions. He was chief pilot for the 14th Airlift Squadron and performed 437th Airlift Wing integration activities for the initial C-17 standup. His space assignments include initial cadre and chief of operations for GPS launch and early orbit activities at the 1st Satellite Operations Squadron, chief of training acquisition at HQ AFSPC, and commander of Clear AFS, Alaska. While assigned to the Air Staff as chief of the training branch within the Operations Directorate, he provided oversight of flying training program elements, the flying hour program, and Euro-NATO Joint Jet Pilot Training.

The Science and Technology of Responsive Space and Its Implications on Risk

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Kirtland AFB, New Mexico

Before 2010, the US shall demonstrate an initial capability for operationally responsive access to and use for space to support national security requirements.

~ NSPD 40-1, Space Transportation Policy, 21 December 2004

Rapid and near universal dissemination of information through the Internet and wireless technology has brought great benefits to society in general and military defense in particular. The primary benefit of this dynamic situation is speed, in terms of enabling rapid deployments, redistribution of resources, an increase in scientific knowledge, and a host of other areas. Conversely, it has also brought new challenges, including a more rapidly evolving threat cycle. Conventional space acquisition timelines, with long cycle times and a focus on mission assurance, are no longer sufficient to counter threats at the rate of proliferation.

In military space, the responsive space paradigm is the key to surviving the dynamic challenges of the future. There is a temptation to consider responsive space only in terms of speed, but this is a limited picture. There are no technical barriers to prevent us from storing a large arsenal of spacecraft with a rapid launch capability and standing ground operations centers, analogous to our ballistic missile fleet. The limiting constraint for this approach is cost, which is why cost mitigation is also an objective of the national responsive space effort. The Operationally Responsive Space (ORS) Office and the Air Force Research Laboratory, as a science and technology (S&T) agent have been working together to address these two goals in tandem, but in so doing have exposed a third barrier, our national willingness to accept risk.

As an example, the Corona program endured 12 mission failures before its first success in mission number 13. The space-based imaging quality was not especially good by today's standards (7 meters resolution), but was infinitely better than a complete lack of capability. Unfortunately, in today's risk-averse environment, a similar program would probably never have made it to number 13. Responsive space must balance speed, cost, and risk if it is to be effective. The prevailing culture in military space acquisition heavily weighs on the risk leg of this triad.

So where are we now? National Security Presidential Directives 40-1 calls for Responsive Space Initial Operational Capability before 2010, but we are not there yet. S&T development has brought us a long way in the past few years, enabling faster integration and lower cost at a reasonable risk point, but by trading off the quality of the resulting products.

Faster, Cheaper, Good Enough

Users have come to expect a certain level of quality in the data they receive, and validated Joint Requirements Oversight Council requirements tend to be extrapolations of existing capabilities. Essentially, we want more of what we already have. However, we know from the failure of National Aeronautics and Space Administration's "faster, better, cheaper" mantra of the 1990s is that we cannot do all three simultaneously. Pick two of three. For ORS, the emphasis is on much "faster" and "cheaper."

If the responsive space paradigm buys us "faster," "cheaper," and "better," the pursuit of exquisite optimality must be replaced with the pursuit of "good enough." We simplify the assembly, integration, and test process to streamline it down to the bare essentials, but this entails a loss of capability and flexibility. The space plug and play avionics (SPA) architecture introduces new features that allow us to buy some of the flexibility back by modularizing spacecraft subsystems and payloads, by enforcing standards on the modules so that they describe themselves, and by designing the overall system to self-organize components automatically using this embedded information. There is a cost, and it shows up in performance due to some increased overhead caused by embedding additional intelligence in components. The trade is worth it.

So how does this impact the unwritten ORS constraint, risk? We do increase our risk, there is no way around it (adding anything causes risk), but SPA can mitigate it. We do this through

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hiding complexity and allowing SPA to manage redundancy (think of it as a rudimentary form of self-healing). When mission design software puts together a mission, *intercompatibility* is an inherent part of that process. Components are constructed to inter-operate, through electronic and software processes that work "under the hood." When a team of technicians assembles the spacecraft, simple tests let them know that everything is put together correctly. Using a new form of a built-in test (we call it "test bypass") allows the spacecraft to be flown virtually on the ground, allowing faults to be exposed and isolated quickly and reliably in ways not possible previously. Testing and qualification can be tailored to a reduced set, based on prior testing of related and trusted configurations. In this case, "trust" is about confidence. When we buy a mouse for our computer, we don't run it through a 200-point checklist and inspect the solder joints, we plug it in. If it does not work, we may suspect the vendor, but not the model of plug and play or the proposition of the personal computer (PC). Aerospace systems can exploit this model as well.

It's All About the Interface

Distribute the risk in a different way by focusing on a modular type of approach intended to reduce complexity.

~ Under Secretary of the Air Force Dr. Ronald M. Sega, 2007

Rapid assembly, integration, and test of spacecraft--turning our spacecraft acquisition process into an assembly line—is made possible through volume (the economies of scale), and volume is possible through opening up the field to multiple competitors, including bus, component, and payload providers. This revolutionized the PC industry—the key is the interface.

For the PC, plug and play led to an explosion of new capabilities and performance enhancements. Volume and competition allows us to put together a PC in our garage using components from 15 manufacturers, and yet it works when we boot it up. It is a combination of hardware specifications and software standards that made this possible, and the road was rocky at first. A standard does not have to be perfect the first time, and we have come to expect that computer hardware interfaces will change with each succeeding generation, about every three years. The architecture model is the constant. The key is that all suppliers change together, and we lock standards down on a reasonable development cycle rather than letting engineers tweak and perfect them into oblivion. And old components, when necessary, are still useable through adapters.

For spacecraft, the answer is SPA. Here is how it works: Think of a system as a set of black boxes, meaning that they perform a function, but we neither know (nor care) how they do this function on the inside. We do not care how complex or simple a computer mouse is on the inside, so long as it works. As in the case of the PC, the black boxes making up a spacecraft must have at least one connector, one that "speaks" the language of plug and play. In your PC, it can be a universal serial bus (USB) or an Ethernet cable. In SPA, we use simple connectors that contain the wires for data signals, power, and synchronization. Like in the PC plug and play, we allow more than one standard, because one size does not fit all (thermometers and high-speed cameras are quite different in power consumption and data rate). We actually used the USB standard from PCs to form the first SPA interface, SPA-U. We later developed a SPA interface based on SpaceWire (a European interface used now in many US spacecraft), called SPA-S. We are working on several other future SPA-x interfaces to accommodate "extreme performance" devices and extremely simple devices. In a large system, we expect multiple interfaces to present, just as they are on your PC. We have engineered the overall system to work fine with a mixture, through bridges and adapters, which are also a part of the concept.

The creation of single-point SPA connectors simplifies interfacing through what we might call the "blue cable/green cable" metaphor. In a manner analogous to a consumer appliance, a collection of SPA black boxes plug together by simply connecting green cables to green connectors and blue cables to blue connectors (they are not really "green" or "blue," it's a metaphor). The idea is that if the connector fits it should work, order not being important, so any open connection point is fine. This is a property we call "topology agnostic," simply meaning that there are many ways to connect together the black boxes, and they are all pretty much equivalent. The system at large works out the configuration details; humans do not have to.

The black boxes are in two basic flavors: endpoints and hubs. Endpoints are pieces of a system that usually do some useful function. Hubs, like the USB hubs in your office PC, allow more endpoints to be connected together. Hubs having both blue and green cable connectors are called bridges.

The black boxes contain electronic datasheets. Technically, they are referred to as extensible transducer electronic data sheets (XTEDS). XTEDS implement a special type of machine-readable interface control document. XTEDS provide a description of everything important about a black box. Any knob that can be turned or set, any measurement that can be read, and command that can be given—they are all in the XTEDS. In fact, if it is not described in the XTEDS, it does not exist, at least from the standpoint of SPA. This concept is key for the data-driven, building block universe that is SPA. Since XTEDS are extensible, the very simplest switch or thermometer is on equal footing with the most sophisticated payload.

SPA is therefore data-driven. The black boxes express their individuality through XTEDS, using special messages that are sent back and forth through a network. Black boxes having equivalent XTEDS are interchangeable, just as two different mice or keyboards are interchangeable in your PC. The messaging system in SPA ensures that the data sent between these black boxes are sent using standard vocabulary terms. We refer to the collection of all the possible vocabulary terms as a common data dictionary (CDD). Just as a standard dictionary contains the words and slang of a language from which all discourse is composed, the CDD contains the expressible universe of terms from which all electronic datasheets are constructed. The terms must be absolutely consistent. The term for temperature must never be garbled, or just as in written prose, the message will not be understood.

This idea of semantic alignment is so important, that we believe the vast majority of problems in the "fog and friction" of integration stem from the lack of any standard for representing and exposing data from aerospace components. As such, software complexity explodes as does the work of aligning interfaces (hardware and software) throughout a network. For this reason, we would be so bold as to claim that no standard interface has truly ever been created in spacecraft avionics. To say that Military Standard-1553 and RS-422 are typical standard interfaces is only partially true. As we pare away the surface effects of a standard connector, standard voltages and signals, we find at the deepest level no constraints (or standards) on how specific pieces of information are represented and managed. We have seen, however, many examples of the incompatibilities that can result, such as the infamous metric/Old English units misalignment in the Mars Climate Observer. This difference, though subtle, is fundamental, probably the most important achievement of SPA, to provide a semantically consistent model driving its plug and play architecture.

Software thrives on such "semantically consistent" standards, and reuse is much more straightforward. In SPA, we have developed a type of middleware that inside a system simplifies the brokering of producers of data (as expressed by the XTEDS of individual components) with consumers. Sometimes, this feature is referred to as a lookup service, bearing a very rough analogy of an internal Google®-like search infrastructure in which a component needing to find all system temperature readings can access them by doing a search for them. This feature, when made dynamic and extensible, can accommodate last-minute changes to the system and promote fault-tolerance (by, for example, adding multiple copies of components that provide a needed service) in a very natural way. In our present system, software applications are plug and play aware and even contain their own XTEDS descriptions. As such, the results of a search may refer to either hardware or software (or both), in effect, blurring the boundaries between the two. The many black boxes of hardware and software needed to form a system can link in a recursive hierarchy, analogous to Russian dolls, through a chain of dependencies. Item "A" may subscribe to item "B," which may in turn utilize information from an item "C," and so forth. An entire satellite system as an appliance can be thought of as the top of this hierarchy. The operator's console of a final satellite, for example, might simply be an XTEDS with a graphical user interface, projected into a ground station, itself extensible and dynamic in response to changing mission needs and features.

Even if we have a collection of these hardware and software building blocks, how do we manage to actually design systems based on them? Certainly not randomly, as monkeys on high-tech typewriters—neither the designs of satellites, nor the works of Shakespeare, could be created this way. We envision an important auxiliary technology referred to as a push-button toolflow. It is common today to purchase products online using sophisticated tools called configurators. These are seen at websites as disparate as Dell, Gateway, and Domino's Pizza®. They capture a user's requirements through a guided process flow involving wizard-like selection dialogs that carefully evaluate the effects of choices, prune away infeasibilities, and eventually produce a potentially unique and buildable product specification. While satellites are not the same as pizzas and personal computers, the underlying theories behind automated component selection, configuration, and integration are mathematically similar. We believe that it will one day be possible to use automated design flows, not just confined to a static system, but distributed and virtually through a web connection. This idea is powerful, as it promotes the possibility of hot-linking to a dynamically changing inventory across a large base of potential suppliers. Today, there may be four star trackers to choose from, maybe tomorrow there will be six. As we add components to our "shopping cart," we can automatically populate our bill of materials, estimate the cost of the overall development, and project the schedule "on the fly." Pushing the "submit" button in this case results in the generation of a complete "DNA code" for a constructible satellite, down to the binary strings of configuration information for each component, their connective relationship, along with the important auxiliary parts of the mashup relating to the test of the final system and its operation (i.e., the user's console).

Testing and assembly could be straightforward. As components are pulled from inventory or arrive through overnight shipping, they may, in extremely time-pressed cases, be added directly to a satellite build, with test scripts executing periodically to evaluate the system under construction. We have created a test bypass concept that institutionalizes the practice known as hardware in the loop. Imagine testing a thermometer using a blow dryer. Simple, but effective, except we have dozens of thermometers, some embedded deeply in a nearly-built system. Test bypass allows us to in effect "bypass" physical reality (hence the name) to provide controlled values of temperature synthetically to the component. Since most systems problems occur at interfaces, test bypass is a very efficient way to isolate and examine components in a complex system. We compare it to the test and debug features commonly available in software code development environments. It would be unthinkable to develop software without these. We apply a similar logic to a six-day spacecraft development, arguing for as many hooks and features as possible to support troubleshooting a complex system.

The Myth of "It Absolutely has to Work"

Mission assurance comprises the majority of the cost of a US government space mission. Launch schedules today are driven by risk analyses, qualification tests, reviews, and approvals—nominally 18 months after a satellite is fully integrated and tested. The fastest development cycles worldwide for a new spacecraft have not broken the 24 month barrier. The responsive space paradigm can enable us to change the way we do business, but we have to be willing to make that change.

There will never be a 100 percent guarantee that a space system will work. The resources needed to gain that extra nine in reliability (say from 99 percent to 99.9 percent) are substantial, and in some cases it only gives us a false sense of security. There will always be the potential for a "failure of imagination," as astronaut Frank Borman put so well in the Apollo 1 investigation hearings. The key is in finding a balance between speed, cost, and willingness to accept risk.

We have merged the requirements from multiple agencies to save cost and schedule, yet as evidenced by the recent cancellation of the National Polar-orbiting Operational Environmental Satellite System, the complexity of managing varying requirements coupled with the attempt to use a technical development program to bridge cultures has done exactly the opposite. Every funding and schedule slip in space programs receives national attention, coupled with challenges in budget volatility, oversight reviews, and changes in direction. In short, the unwillingness to accept the possibility of failure actually ensures it.

Not the Revolution in Military Affairs We were Expecting

We have been trying to force a revolution in military affairs from the top down since the 1997 Quadrennial Defense Review, emphasizing information and command and control capabilities as the means to enhance joint operations. Net-centric warfare was supposed to change everything, to eliminate the fog of war and allow our forces to act as one organism, to somehow transcend Clausewitz. In practice, this has led us to oscillation between the various permutations of centralized and decentralized control and execution.

Historically, though, it is often the technology itself which is the driver of new paradigms. Missile warfare ended the age of the battleship and made the USS Wisconsin a museum piece. RMAs are often painful, because they require us to adapt in multiple areas simultaneously. We believe that the technology of SPA has that kind of power. The limitations of funding, schedule, S&T challenges, while not insubstantial, pale in comparison with the challenge of changing a culture.

We have made outstanding progress on the science and technology enablers for SPA in the past few years. We have demonstrated a powerful responsive space capability in the laboratory, and we are taking it to the next step with AFRL's Advanced Plug and Play Technology Bus program, to demonstrate the architecture on-orbit, and to simultaneously inculcate the approach into industry. However, our culture, our ability to accept the changes inherent in this new paradigm, lags behind the S&T. Yet we must adapt, or be left behind.

Can we find a balance between quality and the level of risk we are willing to accept? We think so, and S&T developed by AFRL and others has opened the door. The question is whether or not we are willing to walk through it.

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Operationalizing Small Space: Challenges of Moving from Research, Development, Test, and Evaluation to Operations

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Operationally responsive space (ORS) is both an ideal type and an emerging reality. As an ideal type, ORS provides a vision of how space can become more relevant at the tactical level of conflict. ORS is quickly gaining relevance to all space activities, and the tenets learned in pursuit of specific ORS capabilities hold increasing promise for application across the space enterprise. As ORS has matured it provides a glimpse into how space systems could be developed, acquired, and operated. For example, the first operational ORS system (ORS-1) is being developed now to support an urgent operational need for US Central Command. If successful, ORS-1 will demonstrate an unprecedented way to field "good enough to win" space capabilities for the warfighter with aggressive cost and schedule mandates. Yet as impressive as the capability may ultimately be, it is critically dependent upon a broader set of capabilities that emerged out of the small space research, development, test, and evaluation (RDT&E) culture at Kirtland AFB, New Mexico centered around the Space Development and Test Wing (SDTW), Air Force Research Laboratory's Space Vehicles Directorate, and the ORS Office. Whether launching Minotaur rockets, conducting satellite command and control (C2) with the Multi-Mission Satellite Operations Center (MMSOC), pushing state-of-the-art plug and play technologies, or using scientific and technical best practices, ORS is leveraging a broad array of Air Force small space capabilities. Nonetheless, this dependence has implications, which must be recognized and addressed. Specifically, the RDT&E-derived small space processes are instrumental for ORS success in terms of cost and schedule. However, they are not currently operationally robust enough to support both a growing ORS portfolio of missions, as well as an emergent small space mission area. This paper will defend that thesis, and offer specific suggestions regarding how to correct this deficiency.

Figure 1. TacSat-3 launch.

Some question whether there is a small space mission area, especially given the lack of requirements in the traditional sense—no one has tasked the Space and Missile Systems Center (SMC) to develop small space capabilities per se. Instead, our legacy RDT&E space enterprise has become increasingly relevant operationally, which has led to heightened expectations. The ability to package increasingly potent capabilities into smaller, less complex (and less costly) systems is pushing small space into a new league. An example from the 1990s may be a good analogue. During the 1990s, after the National Reconnaissance Office (NRO) had been officially acknowledged, we openly discussed the differences between Air Force Space Command (AFSPC) and NRO as being between "white" and "black" space. However, we soon found this distinction to artificially define seams, and recognition of a new category called "gray" space characterized space systems that could support both "white" and "black" space requirements. Space-based radar and the transformational communications satellite were examples of this gray space.

A similar parallel seen in small space today is the distinction between designating a mission as either "RDT&E" or "operational." The designation leads to divergent development, acquisition, test and operational processes, which in general leads to less oversight, redundancy, and rigor for RDT&E systems. The allure is faster, more cost effective mission design, development, acquisition and ultimately fielding to operations. As noted, advances in technology are making RDT&E systems much more capable—to the extent that combatant commands (COCOM) are increasingly interested in the capabilities small space can bring to the fight. Consider just a few of the recent or current small space missions. The Experimental Satellite System-11, known as XSS-11, was launched in 2005 as an AFRL experiment to gain insight into proximity operations. It was developed using RDT&E processes and launched and operated using RDT&E boosters and C2 systems. Yet XSS-11 was vital to the development of the emergent space control mission area. Do warfighters today care about the lessons learned from XSS-11? We suspect so, but it was only the first in a trend. TacSat's 2 and 3 followed, with TacSat-3 providing hyperspectral imagery to COCOMs.

AFSPC is conducting initial planning to support a transition of TacSat-3 to operations after the one-year experiment concludes. The new Minotaur IV "RDT&E" rocket is preparing to launch the Space-Based Space Surveillance System (SBSS) and the Hypersonic Technology Vehicle-2A missions. And of course, the first ORS satellite is being developed now. Determining the right balance between rapid, agile processes typically associated with RDT&E system development and the more rigorous, yet slower (and costly), traditional processes is a key challenge for responsive space missions.

Clearly, the answer to "how much" operations processes cannot be none; the importance of these missions dictate that we have the robustness required to meet warfighter needs. ORS-1 was identified as an urgent operational need; the "urgent" designation requires leveraging the right RDT&E processes, while the "operational need" mandates operational rigor and robustness. The challenge is finding the proper balance across the full spectrum of functionality—development, acquisition, testing, logistics, training, mission assurance, operational procedures, contingency operations, and so forth.

Consider one segment of the small space enterprise; launch systems, which primarily leverages Minotaur rockets developed in the Rocket Systems Launch Program (RSLP). RSLP was established to oversee safe storage and handling, aging surveillance, and safety of flight for excess intercontinental ballistic missile (ICBM) motors and components to support both test launch requirements and the operational ICBM fleet (as required). Several recent events provide valuable insight. First, a closer look reveals that since the RSLP assets were declared excess to operational need in the early 1990s (Minuteman) and 2000s (Peacekeeper), the assets were dropped from official Air Force supply processes. While this made sense from the perspective that no one would be requesting those assets to replace depleted inventory, the Air Force lost the ability to positively control the inventory of RSLP assets associated with the nuclear enterprise—a lesson we have recently relearned across the larger Air Force. We can and must be able to track critical assets at all times to include RSLP motors and components. Second, the handling of these critical launch assets requires the consistent application of technical orders. General C. Robert Kehler challenged the SDTW leadership during their inspector general outbrief to strictly follow ops procedures with the admonition, "you can call it a target, you can call it test, but it's operations!" Given the necessity to launch safely and successfully, this is wise counsel—no matter what the purpose. Lastly, the inability to appropriately resource the system development and mission assurance of the Minotaur IV was assessed by multiple independent review teams as one of the primary root causes for recent launch delays, costing the larger space enterprise well in excess of $100 million. In response, senior Air Force leadership has made robusting the small launch capability one of SMC's top priorities for 2010.

Robusting the small launch capability means we must be able to launch Class A payloads if required. We can see the implications of this in figure 2 below. Using research, development, test, and evaluation heritage launch processes with Minotaur 1, AFSPC has a relatively affordable launch capability with a high success rate. With the expanded operational importance of key payloads such as ORS-1 and SBSS, we require a more robust operational launch capability such as point 2 in figure 2 below. The intent is to hit the "knee in the curve" for the most operational robustness while keeping costs relatively affordable. Once ORS systems have demonstrated their worth and we achieve the ORS future state of having many payloads available to launch at a quick pace, it may be possible to accept significantly more risk to achieve stringent cost and schedule goals, such as the future ORS state at point 3 below.

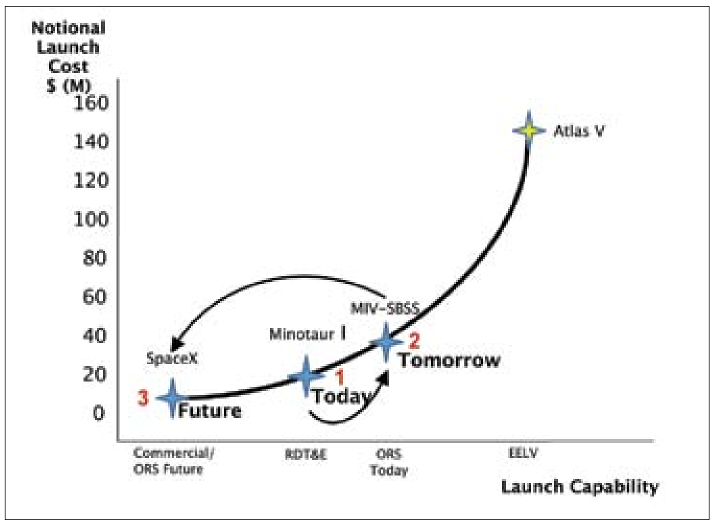

Figure 2. Small launch capability, launch Class A payloads.

Conversely, as the ORS-1 satellite has experienced cost growth, both the AFSPC commander and the secretary of the Air Force have pushed hard on wing leadership to meet cost and schedule goals. Meetings with key congressional staffers have only reinforced the need to develop capabilities cheaply, that are "good enough to win."

The fundamental question is whether the "good enough to win for RDT&E" with its rapid, agile strategy can be leveraged to make the leap to "good enough to win" for the warfighter with enough operational rigor to ensure mission success. These messages are in tension, but not in conflict; the importance of the mission sets in small space requires the underpinning of operational rigor, but we must be able to rapidly deploy these capabilities in a cost effective manner. While this seemingly is the impossible task of "having your cake and eating it too," this tension presents a unique opportunity to reexamine the way we acquire and operate space systems. ORS provides the impetus to evaluate every aspect of our acquisition and operational processes and develop a new "playbook" that exploits the strengths of operational and RDT&E communities. To overcome the weaknesses of the past and build operational robustness into the inherently flexible RDT&E processes, we must:

1. **Recognize an ounce of prevention is better than a pound of cure.** While the cost goals of ORS seem unobtainable when built upon an operational foundation, the opposite is closer to the truth. Wise early spending to build an operational foundation for ORS will significantly reduce downstream costs. While prescience of future ORS needs without firm traditional requirements is not a trait highly rewarded by AFSPC programming budget drills, it is nevertheless required; and therefore will likely have to be driven top down. We have clearly learned from "big space" that lack of resources at the initial stages of space system development and acquisition costs us in spades when we experience mission or acquisition failure. In a recent small space example, the ORS-1 satellite build decision was made in July 2008 with funding contingent on Congressional approval for the reprogramming of funds. Naturally, when delays were experienced with the reprogramming, the program lost momentum and incurred delays. When a program is intended to deliver a space capability in less than two years, it is vital that all aspects of the program are "ready to go" at program initiation.[1]

2. **Identify the processes to apply the "ounce of prevention."** While ORS has blanket waivers from the JCIDS requirements process, some of its supporting architecture pieces do not (such as launch and C2). AFSPC needs to deliberately review all small space processes across the life cycle to determine where the most bang for the buck is in terms of robusting the mission area. Some will require only money but preserve rapid schedule ability (i.e., preparing the infrastructure that ORS can leverage) such as improved logistics processes, expanded up-front launch mission assurance, full acquisition funding at program initiation, and so forth. Other processes may take money and time, such as full blue suit operations. Alternative operational constructs should also be assessed, especially in the area of satellite operations. With the future of satellite operations increasingly migrating from telemetry, tracking, and commanding (TT&C)-type operations to mission planning, perhaps the national and RDT&E model of contractor TT&C with blue-suit mission planning might be the best approach. If an existing process is not clearly providing value, it should be jettisoned. For example, the program executive officer of space waived the requirement to pursue certified earned value management reporting for ORS-1, as the very timelines we intend to support are faster than the certification process required of this financial data. Similarly, much program office and HQ AFSPC time was squandered trying to ascertain exactly which test processes would apply, and whether a test and evaluation master plan was required. The initial default answer across the major command and center functions seems to be that unless told otherwise, standard Air Force processes must apply. We must do a focused review on all AFSPC functional processes to determine which are absolutely essential to apply to ORS missions—with the burden of proof on the functional to demonstrate why their process is necessary.

3. **Build an ORS sandbox.** Nevertheless, we will undoubtedly find that many of the functions needed for big space are still required for small space, but they do not necessarily need to be done in the same order. In fact, many must be done in advance to be able to meet the timelines required. For instance, we must have the tasking, processing, exploitation, and dissemination (TPED) architecture in place for future versions of ORS-1. We must have frequency approval pre-approved for space downlinks. We must have satellites that fly on MMSOC. We must build an ORS box that bounds the requirements in advance to speed approval; if an ORS mission requirement comes through which fits in that box, it is ready to go. A key part of the ORS architecture is defining the standards that future responsive space systems must comply with; space common data link and MMSOC are only two parts of the standard architecture that are coming online now. We must continue with plug and play satellite buses and payloads. The tasking system for ORS-1, VMOC, must be leveraged for tasking other ORS missions beyond infrared imaging.

4. **Leverage the broader space enterprise.** Interestingly, the 1990s "gray" space category forced unprecedented cooperation between two historically separate space development processes (NRO and AFSPC).[2] Close collaboration between acquisition and operations is likewise essential to ensure the up-front integration is successful. With the ORS-1 satellite, 1st Space Operations Squadron (1 SOPS) operators work closely with both the Space Test

ORS provides the impetus to evaluate every aspect of our acquisition and operational processes and develop a new "playbook" that exploits the strengths of operational and RDT&E communities.

Squadron RDT&E satellite operators, as well as the Responsive Space Squadron acquisition arm to ensure that once on orbit, 1 SOPS will be ready. The collaboration required is not just within AFSPC or even the Air Force; we must also successfully integrate our programs with a TPED architecture that includes both Army and Navy capabilities. This means we need to learn how to test across an integrated, joint system. Our culture must embrace being part of a broader mission area; too often each organization focuses on what they do as "the mission," to the detriment of the broader collaboration needed for small space and ORS. Further, the resource constrained environment we face necessitates collaboration since no organization will have the resources to bring it all together. Within the specifics of the acquisition piece, for example, we are looking at how to transition from the ORS "jump ball" approach of picking a single agency to execute an urgent need, to an "all star" team where the Air Force may execute the majority of the effort, but will supplement with key external partners for a joint team.

Small space capabilities and ORS requirements are blurring the line between operational and RDT&E satellites. Small space technologies and budget realities will only accelerate this trend. ORS-1 is a critical satellite to meet COCOM requirements, but perhaps its most important function is to highlight the limitations in our current processes. By bringing to the forefront the functional requirements that drive cost and schedule, we may carefully consider the cost/benefit tradeoff of current operational and acquisition processes. Further, ORS-1 is reliant upon a small space architecture that must be robust enough to support operational missions. The ORS Office ultimately hopes to have enough capabilities "in the barn" that they can take increased risk and avoid the increased robustness that this paper argues is necessary, driving down both cost and schedule. That may be the case in some end-state, but that is not the state we find ourselves in today and in the near future. To the extent ORS is successful in the near term, it will provide capabilities that are few in number but critically important. In the end, some operational robustness must be relaxed, and some RDT&E processes must be strengthened. May we have the wisdom to determine the right balance.

Notes:

[1] All aspects must include ops procedures, logistics processes, defined risk acceptance and associated mission assurance, reporting requirements, test requirements, etc.

[2] Nonetheless, the partnership did not bear fruit with space radar, perhaps because of the lack of full commitment on both sides to a joint program.

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Prior to his current assignment, Colonel Wilson served as the commander, Space Development and Test Wing overseeing 1,000+ military, government civilians and contractors responsible for delivering small, responsive space capabilities to users across the national security space community.

Colonel Wilson entered the Air Force in 1985 as a graduate of the USAFA. Colonel Wilson has been involved with the acquisition of satellite command and control systems, space surveillance software upgrades, ground antenna development, design and testing of nuclear hardened communications equipment, and a variety of advanced technology development projects.

Col Jeff Haymond (BS, Aeronautical Engineering, United States Air Force Academy [USAFA], Colorado; MS, Mechanical Engineering, University of Tennessee; PhD, Economics, George Mason University [AFIT]) serves as the vice commander of the Space Development and Test Wing, Kirtland AFB, New Mexico. The wing's mission is to develop, test, and evaluate Air Force space systems, execute advanced space development and demonstration projects, and rapidly transition capabilities to the warfighter.

Colonel Haymond entered the Air Force in 1985. He initially served as a propulsion test engineer for F-16/B-1/F-22 aircraft and transitioned to the space environment with an National Reconnaissance Office operations tour. Next, he led headquarters Air Force Space Command planning for the Satellite Control Network and Counterspace mission areas, before returning to the USAFA for a teaching assignment and AFIT PhD follow-on. Colonel Haymond returned to the space arena to work Space Commission implementation, and subsequently managed the space and missile legislative portfolio for the Office of Legislative Liaison. He returned to space operations as the director of operations and commander of the 1st Air and Space Test Squadron and then as deputy commander of the 30th Launch Group, Vandenberg AFB, California.

Operationally Responsive Space: Enabling 21st Century Combined Space Operations

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Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after they occur.[1] ~ Giulio Douhet

Italian Air Marshal Guilio Douhet's quote is as apropos today in the early 21st century as it was back in the early 20th century, especially with regard to contemporary space operations. Within the US space community today, operationally responsive space (ORS) provides the opportunity to leverage our allies' expanding interest and capabilities in space.

ORS can potentially contribute to combined space operations from the following perspectives: the logic of international cooperation, US space policy; the precedent of US multinational acquisition/sales/operations; and the business model used by Surrey in creating the small satellite based Disaster Management Constellation.

Besides the F-16 fighter, the US military has partnered with allies in the sales and acquisition of systems such as the TRIDENT II (D5) fleet ballistic missile and the Aegis weapons system, as well as aircraft such as the F-35 Joint Strike Fighter and the C-17.

North Atlantic Treaty Organization (NATO) will be used as a case study to examine the advantages and challenges of ORS-based combined space operations. While NATO serves as a good example, this same logic could be applied equally well to other historically close US allies such as Australia, Japan, South Korea, and others.

The Joint ORS Office was recently created to develop and field space capabilities to assure "space power focused on the timely satisfaction of joint force commanders'(JFC) needs."[2] In other words, the ORS Office is developing both the concepts and technology to allow for rapid development, deployment and operation of space assets necessary provide capabilities in support of JFCs.

Today, JFCs are in fact combined force commanders conducting military operations with US and coalition forces. Seldom has this been more in evidence than in the combined operations supporting Operation Enduring Freedom and Operation Iraqi Freedom. Figure 1 shows that there are numerous operations being conducted globally, involving coalition partners.

To improve support to contemporary operations, the space community must evolve to supporting near real-time operations. The innovative concept of operations and technology being developed by the ORS Office coupled with the combined/coalition nature of modern military operations provides a unique opportunity to anticipate the evolution of 21st warfare. This is especially true of the small satellite based ORS capabilities and related cutting-edge systems. Small satellites can potentially offer high resolution and hyper-spectral imagery. Other capabilities could include communications and signal intelligence payloads.

The cost-effectiveness of small satellites is often questioned because the low Earth orbit (LEO) they typically use imposes operational limitations. This is due to the fact the "loiter" time of a satellite over a particular area is shorter for LEOs than for higher orbits. Thus, a constellation of small satellites in LEO requires more satellites than a constellation of satellites in higher orbits. The whole debate is reminiscent of the 'high/low' fighter mix discussions that ultimately led to the development of the highly successful lightweight fighters, the F-16 and F/A-18.

Harnessing the power of established partnerships will allow the US to harness the potential of small satellites in support of theater military operations. Pulling a page from the highly successful F-16 multinational fighter playbook as a very successful program, we should enlist our closest allies as partners in the operational use of ORS-derived constellations.

Mate 1st Class Bart Bauer, USN

Figure 1. The multinational Combined Task Force One Five Zero (CTF-150) operations currently taking place in the North Arabia Sea to support Operation Iraqi Freedom.

The Logic for Cooperation

Warfare in the 21st century continues to be an alliance/coalition effort. Admiral Mike Mullen, formerly the chief of naval operations and the current chairman of the Joint Chiefs of Staff, articulated the logic for cooperation with his "1,000 Ship Navy" construct (emphasis added):

> We talk about a "*thousand ship Navy*." That's not just our *ships*. It's an *international fleet* of like-minded nations participating in security operations around the world.[3]
>
> No matter how large or small your navy or coast guard may be, we all face similar internal constraints *like shrinking budgets, aging equipment,* and populations that may not be attracted to military service. Our level of cooperation and coordination must intensify in order to adapt to our shared challenges and constraints. We have no choice in this matter, because I am convinced that nobody—no nation today—can go it alone, *especially in the maritime domain*.[4]

Admiral Mullen bases his case for cooperation with allies on shared challenges and a common desire for freedom. When satellites are substituted in place of ships and space for maritime, the logic for cooperation remains sound as demonstrated by the following:

> We talk about a "*hundred satellite constellation*." That's not just our *satellites*. It's an *international constellation* of like-minded nations participating in security operations around the world.
>
> No matter how large or small your nation may be, we all face similar internal *constraints like shrinking budgets, aging equipment,* and *transforming our militaries*. Our level of cooperation and coordination must intensify in order to adapt to our shared challenges and constraints. We have no choice in this matter, because I am convinced that nobody—no nation today—can go it alone, *especially in space*.

Using NATO as an example, the following countries have space capabilities with security and defense utility: the US, Canada, Great Britain, France, Germany, Italy, and others. These countries have capabilities ranging from satellite communications to high resolution (1 meter or better) all weather day/night intelligence, surveillance, and reconnaissance (ISR) satellites. The logic for an international "100 Satellite Constellation" is as strong as Admiral Mullen's logic for an international "1,000 Ship Navy." To paraphrase, a "100 satellite solution" for ORS does not mean just the satellites. It's an international constellation of like-minded nations utilizing their space capabilities to support security operations around the world. The common challenges of shrinking budgets, aging equipment, and the need to transform our militaries require cooperation and coordination—especially in space. While ORS enabled combined space operations may be considered logical, additional factors such as policy are required for any implementation of such a capability.

US Space Policy

An examination of the most recent US National Space Policy reveals that international cooperation for national security purposes is allowed. The following quote supports this assertion (emphasis added):

> *The US government* ***will pursue****, as appropriate, and consistent with US national security interests,* ***international cooperation*** *with foreign nations and/or consortia on space activities that are* ***of mutual benefit*** *and that further the peaceful exploration and use of space, as well as* ***to advance national security****, homeland security, and foreign policy objectives*.
>
> ~ US National Space Policy, 31 August 2006

While current US Space Policy clearly allows for international cooperation that is the underlying basis for ORS enabled combined space operations, implementation would be complex and time consuming.

US Multi-National Precedents

Many precedents can be found for international cooperation in systems acquisition, sales, business, and military operations. The F-35, also known as the Joint Strike Fighter, is an international acquisition program involving a total of nine nations: the United Kingdom, Italy, Netherlands, Turkey, Canada, Denmark, Norway, USA, and Australia.[5] The F-15, F-16 and the E-3 Airborne Warning and Control System (AWACS) are examples of international sales of US systems. The F-15 fighter aircraft is flown by six nations: Israel, Saudi Arabia, Japan, South Korea, Singapore and USA,[6] while the F-16 is flown by 24 nations including: Bahrain, Belgium, Denmark, Egypt, Greece, Indonesia, Israel, Netherlands, Norway, Oman, Pakistan, South Korea, Poland, Portugal, Singapore, Taiwan, Thailand, Turkey, USA, and Venezuela.[7] The E-3 AWACS is flown by four nations: France, Saudi Arabia, the United Kingdom, and the US.[8] In addition, NATO bought the E-3 AWACS and has flown it since 1982.[9] It involves 15 NATO countries: Belgium, Canada, Denmark, Germany, Greece, Hungary, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Spain, Turkey, and the US. The United Kingdom also contributed to the program, but decided to create its own unit of E-3D AWACS aircraft. All these countries, together with the United Kingdom, participate in the multinational NATO Airborne Early Warning and Control Force.[10]

Figure 2. NATO Airborne Warning and Control System.

With regard to precedents involving a space system, NATO satellite communications (SATCOM) is an example of international acquisition, sales, and operations. This NATO heritage in space goes back 40 years. Since 1967, NATO has utilized communications satellites as part of its command and control architecture.[11] The initial NATO I satellites evolved throughout the 20th century into the NATO II, NATO III, NATO IV-A, and NATO IV-B classes of satellites. These early variants of NATO SATCOM were procured and operated as part of the US' Defense Satellite Communications System. NATO's latest program for its geo-stationary communications satellites is known as NATO SATCOM Post 2000. Great Britain, France, and Italy are providing this current generation. Today, as NATO's 28 members are engaged in operations from Bosnia to Afghanistan, NATO's need for space support to theater operations is as strong as ever. In addition, NATO members are actively transforming their militaries and developing their own space capabilities.

Coalition ORS can take advantage of international business model much in the same manner that Surrey Satellite Technology Ltd did for its Disaster Management Constellation (DMC).[12] The heart of Surrey's DMC concept of operations is cooperation of an international consortium because while many countries can afford a single small satellite, most cannot afford an entire constellation of satellites. Therefore, each partner country involved in DMC agreed to buy a small satellite to own and operate while sharing the data from its satellite with the other DMC partners during and after natural disasters. This arrangement provides partner countries the benefits of a constellation at the price of only a single small satellite. The Surrey model also provides opportunities for larger block buys of small satellites than would be the case of a US only ORS-derived constellation. These block buys would stimulate the satellite and launch industries while providing economies of scale would and a resulting lower satellite cost.


Figure 3. NATO Military Committee.

Since the mid-twentieth century, military operations have become increasingly joint which the Department of Defense Dictionary defines as operations in which elements of two or more military departments participate.[13] Since the 1990s, military operations have also become increasingly combined which is defined as involving two or more forces or agencies of two or more allies.[14] Military operations in Afghanistan are a case in point. The International Security Assistance Force (ISAF) was established under the authority of the United Nations (UN) Security Council in 2001. NATO took command of ISAF in August 2003 at the request of the UN. These forces are comprised of 85,000 troops from 43 countries. These forces form the basis of 26 provincial reconstruction teams.[15] A summary of maritime operations in support of Operations Enduring Freedom and Iraqi Freedom, reveals the combined nature of modern maritime operations: ships from Australia, Canada, France, Germany, Great Britain, Italy, Netherlands, New Zealand, Pakistan, Portugal, Spain, Turkey, and US have participated.[16] Australia, Canada, France, Germany, Great Britain, Italy, Netherlands, Pakistan, Portugal, Spain, and Turkey also possess space capabilities; eventually the combined nature of modern military operations will extend to the space systems used to support these types of operations.

Further precedent to be considered is the level of capability to be found in latest commercial space systems. As previously noted, numerous NATO member nations have demonstrated the technical skill and knowledge to design, build and launch imaging systems with better than one meter resolution. For example, Germany has successfully launched five synthetic aperture radar satellites (SAR) as part of a satellite reconnaissance system known as SAR-Lupe. These satellites each weigh 720 kilogram (kg) and provide day/night all weather imagery at approximately 0.5 meter resolution.[17] SAR-Lupe is Germany's contribution to the emerging European Reconnaissance System in which France will be allowed to use the German SAR-Lupe radar system and in return, Germany will be able to access the French optical HELIOS II satellite system.[18] In addition, Israel reportedly employed new intelligence-gathering and strike systems, namely the 290 kg Ofeq-7 reconnaissance satellite's high resolution imagery supporting F-16I aircraft to precisely attack a target thought to be a Syrian nuclear facility.[19]

NATO: A Hypothetical Case Study for ORS Enabled Combined Space Operations

NATO's leadership and participation in operations such as the ISAF in Afghanistan make NATO a logical partner in ORS. As mentioned previously, the logic for a NATO ORS closely parallels the logic used by Admiral Mike Mullen when he articulated the rationale for a "1,000 Ship Navy." Many NATO nations have militarily useful space capabilities. Surrey's DMC model could also be used to implement a NATO ORS. Hypothetically, if each of NATO's 28 member nations agreed to buy and operate a single small satellite, then 28 satellites could be available for use in NATO operations such as in Afghanistan, Kosovo, the Mediterranean or other security operations. Thus, as a case study, a hypothetical NATO ORS capability provides insights to military and economic benefits, as well as insights to the political and technical challenges that must overcome.

Potential Military Benefits

Hypothetically, these 28 satellites could be used to populate two different types of constellations—one for communications and one for ISR. Two constellations, each consisting of 10 to 12 satellites could provide significant coverage and support to NATO (and national) forces. Under US leadership, NATO member nations would gain invaluable experience with space support to their fielded forces. Additionally, a NATO ORS would also be an additional venue for improving interoperability, continuing transformation of allied militaries and further

SpaceX has deliberately designed its launch vehicle systems so that launch site operations are simple, quick, and efficient.

cementing historical ties. Furthermore, a NATO ORS could provide member nations an added means of making meaningful contributions to NATO operations, one potentially without the domestic political challenges of troop contributions.

The relatively large number of satellites of this example would allow graceful degradation of capability. Moreover, it would also provide deterrence since the larger the number of satellites in a constellation, the smaller the impact the loss of any single satellite. A coalition constellation presents challenges to a would-be attacker in ways that an attack on a national constellation does not. A coalition or alliance can bring to bear diplomatic, economic and, if necessary, military responses to an attack in space on a scale greater than any single nation. On the other hand, it can reasonably be envisioned at some point in time, an individual nation might have valid domestic political constraints on the use of its satellite(s) thereby prohibiting their use to support an alliance or coalition operation. In such a case, this nation could lose access to the capabilities of the constellation, while the alliance/coalition retains significant capability.

Potential Economic Benefits

This NATO example demonstrates the opportunity for block buys of small, yet capable, satellites. The potential economies of scale created from such block buys could result in a price tag per satellite in the low tens of millions of dollars. Arguably, this level of cost could make purchasing individual small satellites more attractive than purchasing a constellation or purchasing a single larger, more expensive satellite, especially for smaller nations or those with little space experience. As demonstrated by the Surrey DMC business model, NATO could gain the benefits of a constellation, with the costs of an individual satellites paid by individual member nations.

Fundamentally, NATO ORS could allow for cost sharing which would lower the cost to individual member nations. Another alternative acquisition model could be for NATO to procure a constellation and create organic NATO space capabilities as with NATO SATCOM. Furthermore, one constellation could be produced for NATO member nations by US industry and the other by European industry. This type of acquisition strategy would allow both US and allied industry to benefit, thus creating the mutual benefit articulated in current US space policy.

Potential Implementation Challenges

While NATO ORS could provide significant military and economic benefits, the implementation of a NATO ORS must overcome significant challenges, both political and technical. One of the primary challenges is in acquiring ORS systems without violating the many national acquisition processes found among NATO members. For the US, International Traffic in Arms Regulations poses the most significant challenge to overcome. However, precedence for a NATO ORS has been set by NATO communications satellites, and the international nature of other programs such as the F-35. A second significant challenge would be the time required to reach a consensus among the 28 members of NATO, for the establishment of any type of new NATO space capability.

Lastly, implementation of a NATO ORS will require the development of new command relationships as well as tactics, techniques, and procedures in order to take full advantage of the capabilities provided. However, NATO could build off of the efforts of some of its member nations to create a space-based European Reconnaissance Program for the European Union under the auspices of European Security and Defence Policy.

Summary

In spite of the challenges inherent in any multinational endeavor, ORS-enabled combined space operations is likely to provide a myriad of compelling economic and military benefits. ORS-enabled combined space operations will enable the US to constructively engage its allies as a means to further cement historical partnerships between like-minded nations. The US can take advantage of "state of the world" technological capabilities in space while simultaneously bringing international cooperation to new levels. Perhaps of more importance is that ORS-enabled combined space operations offers the potential to maintain the freedom of space via deterrence inherent in coalitions. Finally, this concept can be a step towards solving the dilemma of funding small satellite based ORS capabilities while at the same time sustaining existing space systems and developing new, unilateral space capabilities. The time has come for the diplomatic, economic and military dialogue with our allies necessary to implement ORS-enabled combined space operations.

Notes:

[1] Marine Corp Doctrinal Publication (MCDP) 1-3, Tactics, chapter 5, Adapting, http://www.au.af.mil/au/awc/awcgate/mcdp1-3/chp5.htm

[2] US, Deputy Secretary of Defense, Department of Defense, Operationally Responsive Space, memorandum, 9 July 2007.

[3] Town Hall, Millington, Tennessee, remarks made at a town hall meeting, 7 September 2006.

[4] 17th International Seapower Symposium, Newport, Rhode Island, 21 September 2005.

[5] Joint Strike Fighter, The F-35 Lighting II, Program, http://www.jsf.mil/program/prog_intl.htm.

[6] aerospaceweb.org, fighter gallery, www.aerospaceweb.org/aircraft/fighter.

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[8] Boeing, http://www.boeing.com/defense-space/infoelect/e3awacs/index.htm.

[9] North Atlantic Treaty Organization, "AWACS: NATO's eyes in the sky," evolution, http://www.nato.int/issues/awacs/evolution.html.

[10] North Atlantic Treaty Organization, "AWACS: NATO's eyes in the sky," fact sheet, http://www.nato.int/issues/awacs/index.html.

[11] 7-17 Comparison of MILSATCOM Systems, Federation of American Scientists, http://www.fas.org/spp/military/docops/army/ref_text/chap07b.htm.

[12] "Surrey Missions: DMC Disaster Monitoring Constellation," Surrey Satellite Technology Ltd., Centaur, data sheet, http://centaur.sstl.co.uk/datasheets/Mission_DMC.pdf

[13] Department of Defense Dictionary, http://www.dtic.mil/doctrine/jel/doddict/data/j/02866.html

[14] Department of Defense Dictionary, http://www.dtic.mil/doctrine/jel/doddict/data/c/01079.html .

[15] North Atlantic Treaty Organization, "International Security Assistance Force (ISAF)," http://www.nato.int/issues/isaf/index.html.

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[17] Wikipedia, SAR-Lupe, http://en.wikipedia.org/wiki/SAR-Lupe

[18] OHB Sysytems, "German SAR-Lupe satellite safely in orbit," http://www.ohb-system.de/gb/News/presse/1912_06.html.

[19] David A. Fulghum, Robert Wall, and Douglas Barrie, "New Satellite Surveillance System Was Key Israeli Tool In Syria Raid" *Aviation Week & Space Technology*, 2 November 2007, http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/ISRA110207.xml.

Ms. Christine Bonniksen (BS, Chemistry, Oregon State University, MS Engineering, University of California, Los Angeles) is director of space access, space programs, and policy; command, control, communications, space and spectrum, Office of the Assistant Secretary of Defense for networks and information integration, Washington DC. She is responsible for oversight, resource review, and strategic evaluations of space launch, space ranges, satellite operations and responsive space. Ms Bonniksen has been part of the Department of Defense Space Programs since she was commissioned in the US Air Force in 1982. She has been active in the development of communications satellites, the global positioning systems, the Evolved Expendable Launch System, and use of national assets for warfighter support leading up and during Operation Iraqi Freedom. Ms. Bonniksen has been a level III certified program manager for over 15 years.

Col Thomas "Dingo" Doyne (BS, Engineering Mechanics, US Air Force Academy, Colorado; MA, Space Systems Management, Webster University, Colorado; MS, Space Operations, Air Force Institute of Technology, Ohio) is currently assigned to the Secretary of Defense Network and Information Integration (NII) as the NII liaison to the Department of Defense (DoD) Intelligence, Surveillance, and Reconnaissance (ISR) Task Force. The ISR Task Force was established by the Secretary of Defense to aggressively provide ISR resources needed now on the battlefield. Formerly he was the Deputy of Space Programs and Policy Directorate where he is responsible for providing broad programmatic oversight of DoD space program matters including acquisition and policy implementation, program management, program requirements, and architectures.

Colonel Doyne was assigned to Air Force Space Command where he served in a variety of operations with the 1st Satellite Control Squadron, the Space Test Program Office, the 19th Space Surveillance Squadron at Pirinclik AS, Turkey, the 45th Space Wing Command Post and the 1st Space Launch Squadron at Cape Canaveral, Florida. Colonel Doyne was also the operations officer of the 2nd Space Warning Squadron at Buckley AFB, operating DSP satellites via the Space-based Infrared System. He had the privilege of commanding the 12th Space Warning Squadron (12 SWS) located at Thule AB, Greenland. The 12 SWS conducts continuous missile warning and space track operations utilizing a phased array radar.

Colonel Doyne's staff assignments include: Headquarters United States Space Command as a war planner and as a member of the command in chief's action group; the Air Staff as a deputy director in the XO Operations Team and deputy director of Strategy Concepts and Doctrine Division; and the National Reconnaissance Office as the staff director for the Aerospace Command and Control Intelligence, Surveillance and Reconnaissance Center's National Capitol Region Operating Locations. Colonel Doyne was also sent to Headquarters US Central Command as an operations planner for Operation Enduring Freedom right after 9/11. Upon completion of Senior Developmental Education in Geneva, Colonel Doyne was assigned to the Office of the Secretary of Defense of Force Transformation and the director of Defense Research and Engineering where he championed operationally responsive space concepts and experiments.

Lt Col Thomas "Solo" Single (BS, Aerospace Engineering, Worcester Polytechnic Institute; MBA, Regis University; MS, Space Operations, Air Force Institute of Technology [AFIT]) is an air and space strategist at the Joint Air Power Competence Centre (JAPCC) in Kalkar, Germany. He serves as the JAPCC's space operations subject matter expert and is responsible for developing air and space power for North Atlantic Treaty Organization (NATO) and the member nations. He is currently deployed to the International Security Assistance Force (ISAF) Joint Command in Kabul Afghanistan, as the chief of ISAF Space Operations.

Colonel Single's operational experience includes ICBM, Space and Air and Space Operations Center weapon systems. He served on Missile Combat Crew and was the chief of electronic warfare officer training at the 90th Missile Wing. In 2000, he attended AFIT and was subsequently selected as one of two Air Force officers to be the first ever service chief interns at Defense Advanced Research Projects Agency. He subsequently served as the chief test analyst at the 17th Test Squadron, followed by the chief of Theater Support, Weapons, and Tactics Branch, at Air Force Space Command (AFSPC) Headquarters.

An internationally recognized expert, he has been an invited guest speaker at more than 50 international events. He has authored numerous articles on NATO and coalition space operations.

Responsive Space Funding Challenges and Solutions: Avoiding a Tragedy of the Commons

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The fielding of the first Operationally Responsive Space (ORS) satellite, ORS-1, in early fiscal year (FY) 2011 will be a tremendous accomplishment for our Department of Defense (DoD) and Air Force. ORS-1 is proving that significant military surveillance capability can be provided using a small satellite fielded in about two years for about $200 million, including space vehicle, launch, and all associated ground infrastructure and operations costs. This accomplishment has already silenced many critics who argued incorrectly that small satellites were merely "toys"; clearly not all militarily useful space systems require decades and billions of dollars to field. Just as the proliferation of unmanned aerial vehicles (UAV) has not eliminated the need for F-22s, small operationally responsive space systems will never completely replace exquisite space capabilities. Due to responsive space's attractive combination of robustness, flexibility, rapid fielding, and affordability, many space analysts and leaders are coming to the logical conclusion that responsive space systems could and should play a growing role in our operational national space architectures. To put it bluntly and in budget terms, less than one percent of the space budget for responsive space and 99 percent for exquisite space is no longer the optimum space architecture for our nation.

Reasons for Responsive Space

The reasons for pursuing responsive space, defined for the purposes of this paper as small satellites that can be rapidly acquired and launched "on demand," remain at least as valid today as when the ORS program was founded in 2007. These reasons/trends will continue to drive our nation's space enterprise toward more responsive space solutions. The four primary reasons for pursuing responsive space remain:

1. **Increasing vulnerability of space capabilities.** While our nation is becoming increasingly dependent on space capabilities, those capabilities are also becoming increasingly vulnerable. As a nation we must "pull our heads from the sand" and avoid a potential space "Pearl Harbor" by addressing this growing vulnerability.[1] The risk can be mitigated by either reducing our dependence on space capabilities or by making our space capabilities more robust. By providing a more dispersed architecture and rapid reconstitution capabilities, responsive space makes our nation's space capabilities more robust against all potential threats, from anti-satellite weapons, to space debris, to launch failure, and even to acquisition failure.[2]

2. **Evolving requirements: Overseas Contingency Operations (OCO).** The military surveillance needs of today are much different from the military surveillance needs of the Cold War, but our space surveillance architecture has limited flexibility and insufficient capacity to meet the evolving needs. For example, in the current OCO it is extremely difficult to "find" the enemy. Demand for sensors such as ground moving target indication (GMTI) that can persistently monitor very large areas and detect "unusual" activity appears to be virtually insatiable because these capabilities enable wide area situational awareness and, more specifically, mitigate some Improvised Explosive Device threats. Presently our space architectures in general remain overly focused on delivering point targets at the highest possible resolution over wide area situational awareness. Small satellites are ideal for persistent wide area situational awareness because they are affordable enough to field the relatively large constellations needed for persistent wide-area surveillance. They provide access to denied areas and, because of the tremendous economies of scale inherent with space solutions, fielding the capabilities required by one combatant commander (CCDR) provides most of the capabilities needed by all CCDRs.

3. **Quantity and quality of space capabilities needed (our "space appetites") far exceed available financial resources.** Due to the many competing budget priorities at all levels of government, this situation will likely continue for the foreseeable future and will encourage innovative thinking and new concepts that can help close critical space capability gaps. These new concepts include innovative business models such as open standards and the Rapid Response Space Works the ORS Office is building at Kirtland AFB, New Mexico. As the Department scales requirements back to match available resources, whether explicitly through the formal requirement processes or implicitly through budget priorities, responsive space systems will play an increasing role. Clearly, in most mission areas, some space capability is better than none. Furthermore, the space industrial base and government workforce expertise are jeopardized by the path our nation is pursuing to acquire only a few exquisite systems; opportunities for "learning" and "practice" within both industry and the government are essential to successfully field systems of any size. The risks facing the industrial base and government workforce could be partially mitigated by shifting more resources to small responsive space. Responsive space is therefore part of the solution to budget shortfalls, not part of the cause.

4. **Technology advances making small satellites more militarily useful.** The same Moore's Law from 1965 that predicted integrated circuits would double in performance every two years (doubling computer processing speeds)[3] also applies to space integrated circuits. Combined with other technological advances, this effect has quickly increased the military utility of small satellites to the point where they now provide excellent value in some mission areas. As the potential capabilities of small satellites increase further, the attractiveness of responsive space solutions as an adjunct to exquisite satellite architectures will increase. Similar favorable trends exist in the launch mission area. If the relative cost of launching small satellites improves due to Minotaur I/IV/V, Falcon, and the standard interface vehicle, while larger systems like the evolved expendable launch vehicle continue to grow in cost, then the trend toward smaller responsive space systems will further accelerate.

Due to these powerful underlying reasons, the trend toward small responsive space systems will continue for the foreseeable future and the budget allocated to responsive space systems will grow. Debate and discussion should center on precisely what capabilities we need, how much of those capabilities we need, and how quickly we need them operationally fielded.

Challenges to Adequately Resourcing Responsive Space

Congress, the DoD, the Air Force, and Air Force Space Command (AFSPC) have been facing the challenge of determining the appropriate funding level for the responsive space enterprise for at least five years. While changing the status quo is always difficult in large organizations (like turning a battleship), there are at least 11 reasons that growing the responsive space budget has been especially challenging:

1. **Flat or declining space budgets.** While the overall defense and intelligence community budgets have grown significantly since 2001, additional funding has been primarily directed toward overseas contingency operations, personnel costs, cost growth in ongoing acquisition programs, and new systems directly and rapidly employable in the current conflicts. A good example of this is surveillance UAVs. While space capabilities are used extensively in the current conflicts, there is little opportunity to quickly modify or augment most existing space capabilities because of the typically long satellite development timelines. So, in general, the military space budget has not been growing. Documented space requirements, "warfighters' appetites," already far exceed the space budget. Ultimately, carving out funding for any new program within the existing space budget requires cuts, cancellations, or delays to other space programs. At least one large space program was terminated in each of the past three program objective memorandum budget cycles.

2. **Nothing transformational in government space programs since global positioning system.** The government space community is accustomed to evolution rather than revolution. The basic list of warfighter capabilities provided from space (intelligence, surveillance, and reconnaissance [ISR]; weather; communication; precision, navigation, and timing; and missile warning) has not changed since precision navigation and timing was fielded in the 1980s. In addition, several attempts at acquiring revolutionary constellations have failed to be fielded (space radar, future imagery architecture, transformational satellite communications system). Others have faced eye-popping budget and schedule overruns (space-based infrared system). Warfighters depend upon space capabilities now more than ever, so there is intense pressure within the space community to avoid any risks that could lead to degraded space capabilities. While understandable and justifiable, that risk aversion must be balanced by willingness to take some risks in pursuit of potentially transformational capabilities such as responsive space. Ironically, extreme risk aversion has been a contributing factor to schedule delays that have resulted in decreased warfighter capabilities when averaged over time. Just as there is a "time value of money," there is also a "time value of capability," both in acquisition and operations. Minimum-risk acquisition is not always worth waiting for or paying for, and in military operations a "good enough" piece of information available within minutes is often more valuable than a perfect piece of information in hours or days. It can be very challenging for leaders to gather the quantitative information needed for informed decision-making in these areas and to lead potentially revolutionary change in a mission area accustomed to evolutionary change.

3. **Misperception that space "takes too long and costs too much."** Fielding space capabilities is technically challenging and costly. Nevertheless, the US has fielded the world's highest-performing space capabilities. Just as no space professional works in the "Non-Operationally Responsive Space Office," no part of our space enterprise wants space capabilities to cost more and take longer. Nevertheless, the misperception that space takes too long and costs too much jeopardizes the enterprise's ability to convince others to increase the space budget to field needed additional capability. Adding responsive space capabilities to the current mix of mostly exquisite space capabilities would provide additional capability and price data points and options. These would help space leaders better explain and justify the entire space portfolio. In the communications mission area, for example, small satellites are not cost competitive with large satellites on a "per channel" basis. The analysis behind that assertion is sound and drove us to the current constellation of large satellites. Small communication satellites can be fielded rapidly and flexibly, though, making them responsive and attractive for reconstitution, spot augmentation, and other unanticipated urgent communication needs. Adding responsive

space capabilities to the current space architecture mix will improve the cost and schedule "bang for the buck," help us better justify the cost and schedule attributes of the current space architecture, or quite possibly both.

4. **Little "cross domain" analysis products or warfighter experimentation.** Office of the Secretary of Defense (OSD) and Air Force budget analysts have limited data available to them to evaluate the value propositions across the air and space domains, making trades difficult. Persistent surveillance, for example, could be provided by a constellation of low Earth orbit satellites, UAVs, manned aircraft, or blimps. The most cost-and mission-effective mix of those platforms has not been recently evaluated. Furthermore, small satellites and blimps are not readily available for warfighter experimentation to evaluate military utility. If they were, the warfighters might demand additional capability, just as they demanded additional Predator capability after initial prototypes were evaluated in the Southwest Asia conflicts and found to be invaluable.

5. **No discrete requirements.** There are no fully vetted and approved joint requirements for ORS as a discrete system. However, the requirements documents for fielded space systems do not purport that current requirements cease to exist after space debris or an antisatellite weapon eliminates a US satellite capability. So there is a requirements basis for robust space capabilities, which implies an ability to maintain or rapidly replace current vital capabilities, but this is not yet specifically spelled out in a single, discrete approved document. US Strategic Command (USSTRATCOM) and AFSPC are leading a joint effort to develop responsive space requirements, but the formal requirements process takes many years of study and analysis. Since there are many approved space requirements that are insufficiently funded, the perception that the current requirements basis for ORS is weak makes it challenging to properly resource responsive space capabilities in a tightly constrained budget environment, even when senior leaders are supportive of responsive space concepts.

6. **Low transaction rates with industry partners.** Whether consciously or not, the exquisite space enterprise seems to be moving toward a depot model with one, or in some cases, two contractors possessing the requisite expertise to field capability in each mission area. That business model leads to relatively few, large, long-duration contracts, limited competition, relatively unresponsive contractors, little innovation and cost control, and likely protest situations on the rare occasions when large new contracts are awarded, since the stakes surrounding each source selection are so high. Under the depot model there are few competitive opportunities, so growth on existing contracts (cost overruns or increased scope) is often the easiest way for a company to capture additional revenue.

7. **Prioritization of "must pay" bills in corporate process.** The analog to reason number six on the government side is that in the DoD corporate budget process "disconnects" are typically funded at a higher priority than "initiatives." Unintended side effects can be to incentivize growth in cost and scope and stifling needed change and innovation. After all, if we funded every possible fix and improvement on the F-15 before funding any F-22s, we would never buy any F-22s. Our space enterprise leaders are faced with very difficult decisions and significant organizational inertia behind the large, established space programs.

8. **Budgets for exquisite satellite systems are easier to defend against small cuts.** A program building a few exquisite satellites is generally less vulnerable to small budget cuts because the effect of a small cut can be disproportionate, in other words a 10 percent cut will often result in much more than a 10 percent decrease in capability. A program building many small satellites or a level of effort or infrastructure program can often absorb a 10 percent cut without as significant an adverse impact on capability. So our corporate budget process unintentionally favors exquisite systems.

9. **Industry watching for decisive government leadership, especially in the budget.** Unlike those of most exquisite space programs, the ORS business model is not based upon awarding one contract spanning many years to a single contractor. The responsive space business model calls for a significantly higher transaction rate, which establishes the "carrot" of capturing future business as the primary motivation to perform well on existing contracts. Most companies seem to recognize the benefits that a more competitive US government space marketplace would provide. Other aspects of the ORS business model may be less appealing to industry, however. In-sourcing of final assembly and test, lower contract values in general, a return to linking fee/profit to risk on cost-plus contracts, interfaces based on open rather than proprietary standards, and open source flight software are concepts that some contractors perceive as threats to their short-term corporate profitability. Others realize that these concepts are necessary to maintain the overall health of the space enterprise over the long run and grow the overall space budget, benefitting many companies and shareholders.

Government acquisition decisions must be based on what is good for the taxpayer and the country, not only on maximizing the prime contractor's near-term corporate profits. The government is the entity likely to benefit most from the ORS business model, and should be eager to experiment with elements of the new model and evaluate risks and benefits. Since the barriers to entry are lower and the US government is not their only customer, the small space industry base is much more vibrant, competitive, and innovative than might be expected from looking only at the US government small space budget. For example, ORS business solicitations have elicited hundreds of excellent proposals from hungry industry partners, including many small businesses. Nevertheless, industry's luke-warm embrace of ORS has influenced decision makers within the government to move more slowly toward responsive space than they otherwise might have. Unfortunately, the government moving slowly on responsive space induces a "wait and see" response from the established space contractors, perpetuating the cycle of moving slowly on responsive space. The bottom line is that industry will follow the money and embrace responsive space fully when, and only when, the government shifts enough budget resources to actually field significant operational capability.

10. **Overselling of ORS concept.** The ORS concept may have been oversold by some who argue that such actions are always needed to get a new program off the ground. The problem with overselling is that it may have contributed to the misperception that ORS is "magically" different from other space acquisition and can make space acquisition faster and lower costs without sacrificing performance. There are many valuable aspects to the responsive space concept, and responsive space solutions typically focus on a different area of the cost/schedule/performance envelope, but it is still the same envelope. With respect to fielding space capabilities faster for rapid reconstitution, if it takes 18 months to build a primary mirror, it is simply not possible to assemble and launch a satellite that uses that component in only seven days unless someone already has a primary mirror "on the shelf." Just as intercontinental ballistic missiles must be acquired before being placed on alert, the nature of the satellite manufacturing business is such that responsive space satellite "war reserve materiel" will be required. The Rapid Response Space Works concept minimizes the cost of needed war reserve materiel by stockpiling components rather than fully assembled satellites, but billions of dollars will still be needed to procure, field, operate, and sustain responsive space architectures/constellations.

11. **"Tragedy of the Commons."**[4] Those who value responsive space concepts as an important and growing portion of our nation's space architecture may all agree on one thing: the funding for responsive space should come out of someone else's budget. ORS was intentionally established as a joint program different from "normal" Space and Missile Systems Center or National Reconnaissance Office (NRO) programs. While there were obvious benefits to that approach, clear responsibility for funding advocacy was not one of them.

Solutions to Securing and Institutionalizing Responsive Space Funding Advocacy

Acknowledging and understanding these challenges is the first step to solving them. The second step is to develop solutions to the funding challenges. Three logical courses of action have been discussed within the responsive space community. All have merit and none are mutually exclusive. The three potential solutions are:

1. **Pursue tactical surveillance as the "responsive space killer application."** Budget advocacy within the department is organized around capability portfolios. The capability portfolio managers seek to maximize capability delivered per dollar spent, "bang for the buck." Responsive space could succeed by demonstrating capability in a mission area in which the argument for a constellation of responsive space satellites is so compelling to the capability portfolio manager that he/she is willing to shift budget from the program(s) of record to the proposed responsive space solution. Electro-optical/infrared (EO/IR) persistent tactical surveillance is one such "killer application." ORS-1 is serving as the perfect prototype for a constellation of 10 ORS-1s in a theater-inclined orbit to provide rapid revisit, plus two to three more available on seven-day call-up for surge and reconstitution. As a necessary element of fielding this "killer application," the entire responsive space infrastructure would be funded and matured.

   Figure 1 depicts a simplistic but nevertheless insightful view of why "one size does not fit all" with respect to DoD and intelligence community (IC) space ISR capabilities and why the DoD may need to field its own constellation of tactical ISR satellites. The x axis represents resolution and the y axis represents persistence—information update rate. Point 1 represents commercially available space surveillance capabilities. Point 2 represents watching "everything, everywhere, all the time," which would meet the requirements of both the IC and the DoD. The tension arises because the space ISR funding needed to reach point 2 would be at least $100 billion per year, far exceeding any budget likely to be available. For the IC, the most important attribute missing from the commercially available data is resolution, so the logical approach in a budget-constrained environment is to build a few exquisite systems and then advocate for more funding to build more of those exquisite systems. From that perspective, the op-

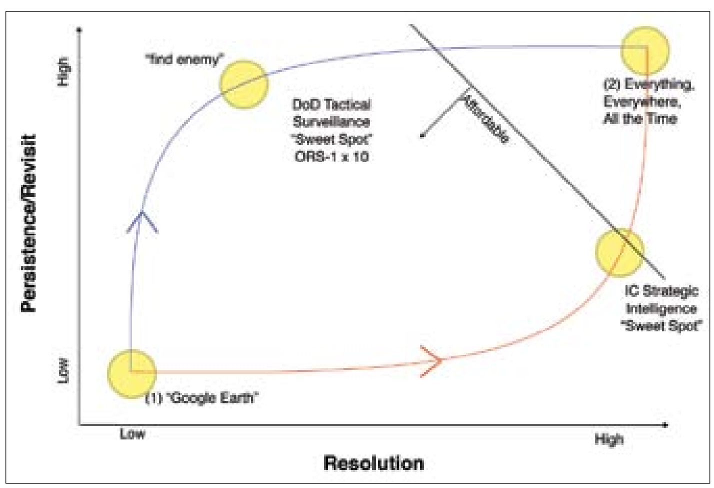

Figure 1. DoD tactical space surveillance needs: One size does not fit all.

timum path from point 1 to point 2 is the lower path. For the DoD tactical user (especially A3/G3/J3) seeking wide area situational awareness, persistence is essential and medium resolution is perfectly acceptable, so the optimum path from point 1 to point 2 is the upper path. A constellation of 10 ORS-1s represents an affordable, much-needed capability along the upper path, the "killer application" for responsive space. The DoD could and should field such a constellation, dedicated to persistent tactical surveillance for the warfighter, by 2015.

2. **Space protection tax.** One of the primary motivations behind responsive space is to increase the robustness of our space architectures. Responsive space accomplishes this objective by enabling dispersed constellations and rapid reconstitution. The established exquisite space program offices have generally not been given specific requirements for "protection" or "robustness." When they are, they will be forced to evaluate responsive space against other means for increasing the robustness of the space capabilities they provide. Conceptually, the Air Force program executive officer for space and NRO director could implement a five percent "space protection tax" on each existing space program that fails to meet certain robustness criteria, as defined by the Space Protection Program (SPP)[5] or another appropriate entity. This tax would fund responsive space and possibly other space protection initiatives. It would incentivize the existing capability managers to evaluate competing methods to meet the emerging space threats and work with the responsive space community to assess the degree to which responsive space could contribute to robustness in each mission area. As an added benefit, these analyses and discussions would focus ORS Office efforts on the mission areas likely to benefit the most from responsive space augmentation and reconstitution. The positioning, navigation, and timing (PNT) mission area, for example, operates in mid Earth orbit and is already well dispersed and redundant, so the five percent tax would probably not be applied to them and responsive space should not focus on PNT.

3. **Build responsive space infrastructure: "U-2 Reconnaissance Wing for Space."** The third potential approach to responsive space funding challenges is to treat responsive space as "essential space infrastructure" analogous to launch and ranges. AFSPC would be the most logical entity to procure, field, operate, and sustain a responsive space infrastructure that included launch vehicles, buses, payloads, and command and control capability awaiting USSTRATCOM call-up. Figure 2 shows how each element present in a U-2 reconnaissance wing has an analog in this "Responsive Space Wing" concept. This "Joint Responsive Space Wing" would logically serve under the operational control of a STRATCOM entity such as Joint Functional Component Command for Space (JFCC Space) (call-up of war reserve capability) and/or JFCC ISR (apportionment of ISR assets). The ORS Office

Figure 2. Reconnaissance wing capability for space.

would continue to mature and demonstrate new capabilities and responsive space technologies. The other services and agencies would supply user equipment and payloads specific to any unique mission requirements, or perhaps other appropriate small pieces of the architecture. For example, the Army could sustain the Kwajalein range for Minotaur V geosynchronous Earth orbit small launch capability. Detailed plans for implementing this vision have been developed. The key missing enabler is funding, and the amount needed to provide an initial operating capability by 2015 based on proven and militarily useful technology such as ORS-1 is on the order of only $1 billion over the Future Years Defense Plan. $1 billion is certainly not a trivial investment, but responsive space should be able to compete favorably within the Pentagon's budget processes because of the tremendous "bang for the buck" and the priorities and principles described in the Quadrennial Defense Review and forthcoming Space Posture Review.[6]

Recommendations and Conclusions

The funding approaches described above are not mutually exclusive and all can be pursued in parallel. To proceed down this path, four of the most important specific actions that could be taken this year are:

1. **AFSPC could operationalize EO/IR responsive space capability.** Operationalizing the capability refers to "procure, field, operate, and sustain." The EO/IR technology used in ORS-1 derives from the proven TacSat-3 spacecraft bus and the proven U-2 optical system. ORS-1 will be launched on a proven Minotaur I launch vehicle. All of this technology is mature and ready to be operationalized. The capability was identified as an urgent need by US Central Command and is clearly needed and militarily useful across the spectrum of conflict. Formal requirements documentation is forthcoming. AFSPC should start building toward a constellation of 10 ORS-1 satellites with some "war reserve" capacity on seven day call-up. Strong funding advocacy is possible from USSTRATCOM, Joint Staff, and OSD, tied to and on behalf of the warfighter's battlespace awareness needs.

2. **ORS Office and program element could accelerate planned activities.** The ORS Office and program element must remain focused on "architecting and demonstrating" ORS systems and concepts. They should accelerate efforts to establish the viability of "plug and play" via a small radar satellite focused on the tactical warfighter's broad area situational awareness mission, that is, GMTI. Longer term, the ORS Office needs to be adequately resourced to demonstrate one on-orbit space system per year and provided with needed functional support and functional oversight, for example contracting authority, so that some crucial needed activities can be responsively and responsibly conducted "in house." Considering the responsibilities and tasks the office needs to perform, they may have outgrown the "big sign, small office" concept and should be sized as appropriate for the task of architecting and demonstrating responsive space concepts. They should not procure, field, operate, or sustain responsive space technologies; those are the functions of the services. Only as a last resort, if the services are unwilling to perform those functions, should the "ORS Office" transition to the "ORS Agency" and follow the Missile Defense Agency model.

3. **Air Force Intelligence could lead a persistent surveillance analysis of alternatives (AoA).** In Iraq and Afghanistan the Air Force is filling the persistent surveillance gap identified in figure 1 using UAVs and MC-12s. Those solutions are working extremely well in those conflicts but will not work well in contested airspace or denied areas. AF/A2 should partner with AFSPC, Air Combat Command, and the joint warfighting community to document the persistent surveillance requirements across the spectrum of conflict. Then they should conduct a cross-domain AoA to determine the best mix of standard UAVs, stealthy UAVs, manned aircraft, small satellites, and blimps/airships to meet those persistent surveillance requirements. The Air Force will be able to use the AoA results to optimize force structure, including fielding a constellation of small GMTI and/or EO/IR satellites if the AoA so recommends.

4. **Space Protection Program (SPP) could conduct robust space capabilities AoA.** The SPP was established by AFSPC and the NRO to increase the robustness of our space capabilities against the threats those capabilities face. Responsive space enhances space protection by offering more distributed architectures and rapid reconstitution. SPP should conduct an AoA that spans the mission areas and evaluates the potential contributions of responsive space and other space protection concepts within our nation's space architectures. At least 10 percent of the space budget should be subject to redistribution as needed to maximize robustness of space capabilities in accordance with the AoA results and recommendations.

The fielding of the first operational responsive space system, ORS-1, in early FY 2011 will definitely be an accomplishment to celebrate, but it is also an opportunity to look forward and move to the next phase of the responsive space vision. Due to the hard work of many in the responsive space community over the past several years, the vision and roadmap leading to fielded responsive space capabilities is clear. We are ready and able to field a "U-2 Reconnaissance Wing for Space" delivering on-demand EO/IR capabilities by 2015, with additional mission areas to follow. The only significant obstacle to moving forward with the responsive space vision is inadequate funding. By working through the strategies and completing the analytic products outlined in this paper the responsive space enterprise should be able to explain the value of responsive space within the department's corporate processes and secure the needed funding to move forward.

Notes:

[1] Commission to Assess US National Security Space Management and Organization, also known as "The Rumsfeld Commission," 11 January 2001, viii.

[2] Department of Defense, Quadrennial Defense Review Report, February 2010, 33-34.

[3] Gordon E. Moore, "Cramming more components onto integrated circuits," *Electronics* 38, no. 8 (19 April 1965): 4.

[4] Garrett Hardin, "The Tragedy of the Commons," *Science* 162, no. 3859 (13 December 1968): 1243-1248.

[5] "US space protection strategy emphasizes cooperation," *C4ISR Journal*, 2 October 2008.

[6] Department of Defense, Quadrennial Defense Review Report, February 2010, 22.

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Colonel Felt served as the operationally responsive space (ORS) program element monitor, Directorate of Space Acquisition, Headquarters, US Air Force, Pentagon, Virginia. In this position Colonel Felt supported the Air Staff and ORS director to resource and defend the revolutionary joint $1 billion ORS space effort dedicated to quickly providing space capabilities to theater commanders.

SMALLER is Better: Technical Considerations for Operationally Responsive Space

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Nature abounds with examples of living things evolving to meet their natural environments. Scientists believe that life on earth evolved from simple, single-celled organisms that gradually metastasized into multi-celled creatures and eventually into large, complex systems. Living creatures today are a mix of these simple and complex systems, but with higher-order species (plants and animals) seemingly dominating the fold. However, the geologic record also shows eras of great extinction—where cataclysmic events such as asteroid impacts or global warming/cooling—have wiped out entire classes of organisms including the dinosaurs. Through these earthshaking periods, the survival and resiliency of simple systems (algae, phytoplankton, insects, etc.) preserved life on the planet and allowed for the eventual restoration of a full ecosystem, including the higher-order species.

Recent natural and man-made threats to US military, intelligence, civil, and commercial space systems have raised the specter that today's space architectures have "evolved" to a position analogous with the dinosaurs—highly optimized systems perfectly suited for the current environment, but unable to adapt to unexpected threats when and if they should arise. Today's debate regarding space protection hinges on the fact that the US currently fields small numbers of large, exquisite satellites that, while incredibly capable in meeting their design requirements, are increasingly susceptible to enemy action, natural space weather hazards, or other forms of deliberate or unintentional interference. Coupled with a decades-long development and acquisition cycle, the US runs the risk of losing its space capabilities in conflict or being deterred from achieving national security goals if these systems are seen as threatened.

Recent Trends in Small Satellite Development

Advances in small satellite development over the last decade have spurred initiatives such as operationally responsive space (ORS) to address both space protection needs as well as the challenge of breaking the current laborious acquisition process. The ORS Office at Kirtland AFB, New Mexico, is chartered to provide "assured space power focused on timely satisfaction of joint force commanders' needs."[1] Current efforts include the ORS-1 satellite intended to augment existing national overhead systems while focused on the needs of Department of Defense (DoD) warfighting commands. The satellite, derived from an existing Air Force Research Laboratory (AFRL)-developed TacSat-3 satellite bus and using off-the-shelf optical systems, is currently being fielded by the Space Development and Test Wing (SDTW) at Kirtland AFB and slated for launch in fall 2010 after a two-year development cycle. Additional ORS Office-sponsored efforts, including the Naval Research Laboratories' (NRL) TacSat-4 tactical communications demonstration, are showing that small satellites (300-500 kilograms [kg]) can effectively meet DoD warfighter needs with cost and schedule parameters more responsive than current high-end space systems—while providing technical performance characterized as "good enough to win." This satisficing requirements strategy, rather than the exhaustive analyses of alternatives and cost-optimization prevalent in DoD acquisition, acknowledges the short (1-3 year) intended operating life of ORS systems while allowing for rapid technology insertion into newer platforms.[2] This approach is akin to "planned obsolescence" in commercial consumer electronics and takes advantage of recent improvements in low-cost satellite subsystems and launch vehicles to achieve reasonable performance at more modest costs.

Despite the attractiveness of currently-planned ORS systems to meet urgent warfighter needs or provide reconstitution and augmentation of high-end DoD space systems, there are limits to what can be reasonably expected from this class of satellites. Any aerospace engineer can tell you that the cost of an aerospace platform is directly proportional to its mass. In this case, the cost of today's 200-300 kg satellite is roughly $20-40 million for a basic design (and upwards of $80-100 million for satellites requiring more sophisticated intelligence, surveillance, and reconnaissance [ISR] payloads) with launcher costs ranging from $20-40 million depending on specific requirements. Including ground command and control, data exploitation, and other infrastructure, the cost of a single ORS mission in this weight class will run somewhere between $50-200 million dollars. While clearly attractive when compared to the billions of dollars required to field a high-end DoD space system, an adversary might checkmate the US in wartime if the cost to negate this space capability is significantly less than its replenishment costs.[3]

There is, however, substantial progress in the area of microsat/nanosat/picosat development that suggests we are on the verge of a technological tipping point for exceedingly small satellites capable of meeting valid operational requirements—while serving as the "microorganisms" for space system survivability.[4] This trend is ultimately enabled by Moore's Law and the increasing processing power that can be delivered in modern microelectronics. Combined with other benefits to related spacecraft subsystems resulting from decreased size, this trend allows for radically different space system architectures to evolve in ways that enhance their survivability, persistence, resiliency, and adaptability.

It's All About Rocket Science

The first American space satellites of the late 1950s and early 1960s were small in size and capability—because both the launcher and space electronics technology of the day would not permit otherwise. As spacelift capability improved, the size of satellites increased along with their effectiveness and their complexity. These trends drove improvements in on-orbit lifetimes and reliability, which in turn drove the demand for improved capabilities resulting in ever-heavier satellites. As satellite mass (and cost) continued to increase, this again drove increased demands for launch vehicle performance and reliability. This "upward spiral" of launch vehicle and satellite cost/complexity is realized today in typical satellite development timescales of over a decade—with costs in the billions of dollars to place small numbers of heavy, complex satellites into orbit for DoD and intelligence community users. But Moore's Law and the power of miniaturization suggests there may yet be another way if we are willing to "think small."

The act of launching a satellite into space is an inherently complex and dangerous process. The term "rocket science" is not casually applied, since the task of accelerating a vehicle to over seven kilometers per second and then operating remotely for weeks, months, or years in near-vacuum (with varying intensities of impinging electromagnetic energy and thermal cycling) requires enormous engineering, planning, and operations discipline. Few non-engineers appreciate the subtlety of the physics involved. The Tsiolkovsky Rocket Equation (which relates the initial and final mass of a rocket to its achievable velocity) is an exponential relationship.[5] The reason for staging on all rockets that achieve orbital velocity is a direct consequence of this fact—the rocket engineer operates on the ragged edge of mass margins and structural materials strength to minimize a rocket's mass to place a given payload into space. The heavier the payload, the more difficult the problem becomes, with a complexity that appears to take on exponential proportions of its own. Simply put, smaller rockets are simpler, require fewer moving parts, and obtain greater structural margins at a given throw-weight based on today's materials technology.

The interaction between satellites and launch vehicles is also a complex one that dominates the technical challenges associated with placing payloads into space. Satellites must possess sufficient structural strength to survive the accelerations from typical g-forces during launch (routinely three to eight times the force of Earth's gravity) while at the same time minimizing the structural mass required to ease performance requirements on the launch vehicle. G-force (or static load) requirements are not the only ones that satellites must endure—they must also deal with severe shocks imparted from staging/separation events and dynamic coupling between the satellite(s) and the launch vehicle itself. The latter concern (dynamic coupling) must be considered when examining interactions between the launch vehicle autopilot, propulsion subsystem, and induced structural vibrations experienced throughout the rocket. One phenomenon is famously known as "pogo oscillation" when experienced on liquid-fuelled launch vehicles, but similar concerns involving other resonant frequency interactions on both liquid-fuel and solid-fuel launch vehicles are also possible.[6] A computational modeling process known as coupled loads analysis (CLA) is most often used to prevent such interactions from causing vehicle damage or breakup in flight; however, using today's methods, a full CLA typically requires 12 to 24 months to complete. Generally speaking, the stiffer the spacecraft is, the easier the technical challenge becomes with integrating the satellite onto the rocket. An "infinitely stiff" spacecraft (for a given, fixed mass) remains the technological Holy Grail for satellite structural engineers.[7]

The Curve that Matters

Figure 1 is a scatter plot of spacecraft first fundamental (resonance) frequency versus mass for a number of small satellites designed and orbited over the past decade (data collected by the author). Two engineering observations immediately stand out. First, the general shape of the interpolated graph is hyperbolic [f(x) = 1/x]), which is not surprising given that specific strength (or strength to weight ratio) of typical aerospace structural materials like aluminum or titanium benefits from the significantly reduced spacecraft volumes achievable at lower spacecraft masses. Put another way, as a spacecraft grows in size (volume) its mass grows proportionally in such a way that the overall spacecraft stiffness that is achievable given the engineering strength of materials goes down—significantly so in the case of satellites weighing in excess of 1,000 kg at rest (1 g condition).[8] The smaller the satellite, the easier the task at hand (almost absurdly so for spacecraft below 50 kg). In layman's terms, just because a model bridge made from toothpicks can hold a mason's brick doesn't mean the results will scale into a full-size bridge given an equivalent load but the same building materials.[9]

The second observation is that the "knee" in this curve appears somewhere in the range of 200 kilograms for a first fundamental frequency above 25-30 hertz (Hz). In practical terms, a spacecraft with a first fundamental frequency above this val-

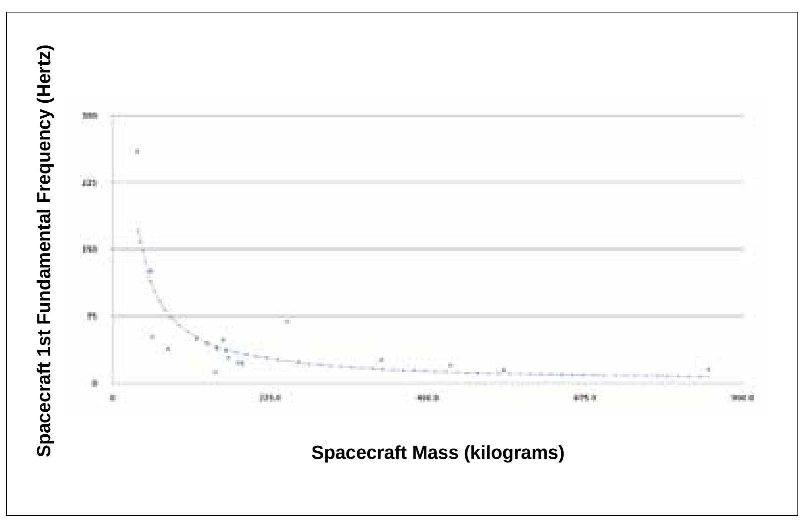

Figure 1. Spacecraft fundamental frequency versus mass (data collected by author). Dotted line shows average frequency (6056 Hz kg/Mass).

ue is much less likely to experience dynamic coupling with its launch vehicle (or just about any launch vehicle in the world's inventory today). Put another way, spacecraft that achieve this minimum stiffness are more easily shifted from launcher to launcher with minimum changes to the systems engineering integration that is required. From the graph, the size (and associated mass) of the spacecraft that consistently attains this minimum are spacecraft weighing 200 kg or less.[10]

Small spacecraft yield other engineering benefits that scale positively with decreasing size and mass. While a small spacecraft ultimately has less electrical power available to it compared to traditional large spacecraft (due to reduced surface area or deployed area for solar arrays), the challenges associated with thermal load dissipation are also remarkably easier. Operating in vacuum, all satellites eventually rely on radiative cooling to maintain operating temperature. On large-volume satellites, complicated subsystems such as heat pipes and preferential placement of hot, energy-consuming components are required to maintain spacecraft thermal balance. The associated computer modeling required to analyze on-orbit behavior is an intensive engineering activity on most large spacecraft programs. By comparison, the distances involved in heat transfer on small satellites are short and relatively straightforward conductive paths. Other spacecraft subsystems benefit from similar decreases in complexity at smaller scales, although this result is not yet universally true (some subsystems have a minimum-size "form factor" given the current state of technology). As always, the cost and complexity of individual satellites scales with their mass and volume.

ESPA-class Satellite Standards and Implications

Over the past decade, a new class of satellites has emerged to take advantage of an emerging set of standards established for the evolved expendable launch vehicle (EELV) secondary payload adapter, or ESPA. ESPA began as a small business innovative research contract with CSA Engineering, Inc., as a jointly sponsored effort of the DoD Space Test Program (STP) and Air Force Research Laboratory's Space Vehicles Directorate to accommodate secondary payloads on EELV. The ESPA ring as designed can hold up to six 180 kg (maximum mass) satellites inserted underneath the primary payload (figure 2).[11] ESPA was demonstrated successfully on its maiden flight in March 2007 during the STP-1 mission flown on an Atlas 401 (figure 2a) and has also been flown successfully as part of the National Aeronautics and Space Administration (NASA) Lunar Crater Observation and Sensing Satellite mission in 2009. In February 2008 the secretary of the Air Force directed that ESPA-hosted satellite operations be normalized to support responsive spacelift; currently, the EELV budget supports one ESPA flight per year beginning in fiscal year 2012.[12]

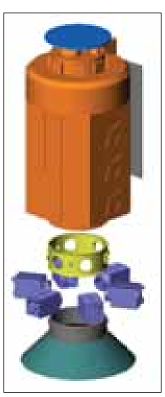


Figure 2 and 2a. Generic EELV ESPA configuration; ESPA first flight configuration on STP-1Launch, 9 March 2007.

Designing satellites to fly on ESPA is not a "natural" activity as any aerospace engineer can attest. Because the original EELV specification left out any requirement for secondary satellites, the ESPA design is a deliberate attempt to minimize impacts to the primary payload by simply raising the satellite 24 inches inside the launch vehicle fairing.[13] This requires the ESPA satellites to hang cantilevered off the ESPA ring, so the primary launch loads (up to 8.5 g's) are transmitted through their transverse axes as compared to traditional satellites which experience their greatest loads in the axial direction. Additionally, the ESPA satellites experience a relatively severe shock environment (up to 400 g's instantaneous at 1500 Hz) due to the stiffness of the ESPA ring and the transmission of the primary spacecraft separation loads. Despite these challenges, the ability to build ESPA-class satellites capable of surviving these launch environments yields substantial benefits. The Ball Aerospace-built STP standard interface vehicle (SIV) is designed to ESPA standards and is compatible not only with ESPA itself, but also readily transfers to launches from Orbital Sciences Corporation's Pegasus, Minotaur I and Minotaur IV launch vehicles (and possibly SpaceX Corporation's Falcon 1) with minimum impact and no structural design changes. In fact, the first launch of SIV is occurring in summer 2010 (along with three other microsatellites designed to ESPA standards) on the STP-S26 small launch vehicle mission using a Minotaur IV launch vehicle with a STP-sponsored multi-payload adapter. This adapter holds the satellites in a traditional (i.e., axially oriented) configuration.

CubeSats Gone Wild

At the extreme low-end of satellite weight classes, a revolution has occurred in the past decade for satellites in the 0.5-10 kg range. This revolution is enabled by technical standards for both the satellites themselves and their launch vehicle dispensers. These so-called CubeSats (named for their basic one-unit [U] design, a 10 centimeter [cm] x 10 cm x 10 cm cube weighing no more than an equivalent liter of water, or 1 kg) were first proposed at the turn of the century to foster educational outreach for high school and college students via hands-on satellite engineering (figure 3).[14] Given the processing power of today's commercial-off-the-shelf electronics,

Figure 3. Cal Poly CubeSat CP-4 photographed by AeroCube-2 (launched 17 April 2007 as secondary payloads on a Russian Dnepr launcher).

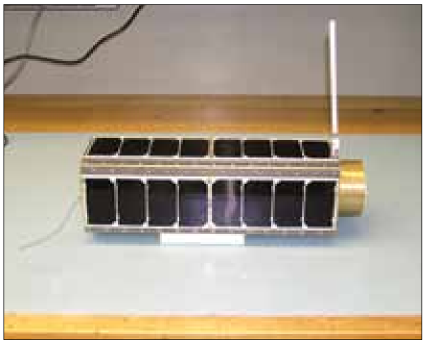

Figure 4. NASA Ames GeneSat-1 (launched 16 December 2006) as a secondary payload on a US Minotaur I launch.

these tiny satellites are enormously more powerful than the early Explorer, Vanguard, and Pioneer satellites. The cost to build CubeSats is incredibly inexpensive—from $25,000 (a basic kit design and do-it-yourself labor) up to $1-5 million for complicated US government scientific projects (with labor and testing as the cost-driver) (figure 4). The cost to launch a CubeSat as a secondary payload is also cheap, typically running from $50,000 to $70,000 for a 1U CubeSat. These satellites are today equipped with miniaturized global positioning system (GPS) receivers, cell-phone digital cameras, reaction wheels, radio transceivers and microprocessors running mobile-device operating systems. Larger 3U CubeSats taking advantage of the full volume of a standard California Polytechnic State University (CalPoly)-Picosatellite Orbital Deployer (P-POD) can now be equipped with deployable solar arrays, antennas, and cold-gas propulsion subsystems.[15] Available power is roughly one watt per 1U cube of surface area, with roughly 1.5 megabit per day of downlink capacity.[16]

A major advantage of CubeSats is their unobtrusiveness to the launch vehicle integration process. A full P-POD weighs just slightly over 5 kg and requires a simple electrical initiation signal to activate a resistive-actuator door release (the satellites themselves are deployed from the P-POD using a simple spring) (figure 5). The genius of the P-POD is the containerization of the CubeSats within a deployment device qualified to NASA Standard 7001 mechanical workmanship standards.[17] In essence, the P-POD serves as a "shipping container" that prevents even a catastrophic CubeSat structural failure from escaping the P-POD and damaging the launch vehicle during flight.[18] Even more importantly, the small size and mass of a P-POD greatly simplifies the launch vehicle CLA process as compared to larger satellite payloads. Whereas even micro-satellites still require detailed computer finite element models (FEM) to numerically approximate a complex system, the P-POD is like a flea on the back of an elephant—CubeSats can be modeled with a simple mass-spring-dashpot approach that outputs a relatively straightforward (and deterministic) transfer function. This dramatically shortens the time required for CLA compared to normal FEM computer simulations.

Figure 5. NASA Ames GeneSat-1 loaded into P-POD.

Critics have argued that CubeSats are nothing more than toys. The rapid growth in small satellite technology over the past decade (approximately 30 CubeSats launched since 2003) challenges this view through the on-orbit demonstration of growing CubeSat utility in scientific and military endeavors. Today over 50 universities worldwide have active CubeSat programs.[19] Various US scientific, defense technology and industry CubeSat efforts are also underway. Leading organizations include NASA, the DoD Space Test Program (STP) within SDTW, the National Science Foundation, the National Reconnaissance Office, CalPoly, AFRL, NRL, US Naval Postgraduate School, US Army Space and Missile Defense Center, the ORS Office, and Boeing Phantom Works. CubeSats' small size, low-cost, and ease of construction have contributed to their proliferation across the aerospace industry. Current example missions include *in-situ* space weather monitoring, technology maturation, astrobiology, atmospheric density measurement, and beyond line-of-sight communications. Additional efforts are ongoing to expand CubeSat capabilities into medium-resolution earth sensing, unmanned ground sensor data exfiltration, tactical electronic support, and humanitarian relief missions. While it is true that physics may limit what small-sized spacecraft may achieve in some mission areas (such as large-optic telescopes for high resolution), the rapid progress achieved to date suggests these limits may be overstated by CubeSat detractors.

Many analysts have also expressed concern that CubeSat proliferation will greatly contribute to today's orbital debris challenges (aka "debris-sat"). Orbital lifetime studies conducted for representative 1U CubeSats shows that uncoordinated reentry will normally occur within one year for orbital altitudes less than 275 km, two years at an altitude of 400 km, 10 years for an altitude of 550 km, and 25 years (the US government orbital debris mitigation standard) at an altitude of 625 km; however, the addition of an inexpensive 100-meter electrodynamic tether weighing less than 0.6 kg can decrease these lifetimes to less than a year for 525 km altitude, 10 years at 800 km altitude or 25 years at 1000 km height.[20] The DoD STP, NASA and AFRL are currently sponsoring technology development efforts for other drag enhancing devices (including extensible "sails" for small satellites) that will be demonstrated as early as summer 2010.[21] These improvements can substantially mitigate orbital debris concerns.

Conclusion

The DoD Strategic Deterrence Joint Operating Concept published in 2004 made the following statements on future space control concepts:[22]

These new concepts, when proven, might replace (or, at a minimum, supplement) our current architectural approach of small numbers of large, expensive spacecraft—the space equivalent of less-complex life forms that achieve resiliency through their ubiquitousness.

> By 2015, space control will be most greatly enhanced by the joint force's ability to use space systems in a highly-networked, peer-to-peer manner—to deny an adversary the easy means of holding critical US space system link, user, terrestrial, or space segments at risk.… This will be accomplished by proliferating, networking, protecting, and integrating each of these segments in a manner previously considered unachievable. The combination of low-cost production combined with miniaturization and shared understanding will enable both response and denial options for strategic deterrence.…
>
> Satellite design will migrate toward small, single-purpose, distributed constellations providing continuous earth coverage. This will deny an adversary the ability to easily target a small number of critical nodes and create a much-needed measure of defensive redundancy. Command and control of these constellations will rely heavily on automated machine-to-machine interfaces. Terrestrial ground support infrastructure will not be stovepiped by specific mission area (i.e., ISR; positioning, navigation, and timing; communications; etc.) but instead will service a variety of functions in a scalable, tailorable fashion.…
>
> To populate, replenish, and rapidly reconstitute these constellations, low-cost responsive spacelift is essential. This capability will allow the US to respond to an adversary [weapon of mass effect] attack by rapidly reconstituting systems destroyed or degraded by enemy action. Responsive spacelift requires mobility and proliferation that reduces an adversary's opportunity to target systems while in preparation for launch. Modular, production-line methods that allow for "mass customization" of satellites, launch systems, terrestrial C2 [command and control] and user segments are required.…

The emergence of small satellites and associated new concepts of operations are bringing these ideas to fruition—both with the space segments (small satellites), as well as the associated industrial base, workforce, and support infrastructure required to make this vision a reality. As just one example of this, the Defense Advanced Research Projects Agency (DARPA) effort on fractionated satellites (DARPA F6) recently awarded a contract to Orbital Sciences Corporation for satellites designed to ESPA standards.[23] DARPA F6 will demonstrate by 2013 the distribution of multiple payloads onto smaller individual spacecraft as well as the decomposition of large spacecraft subsystems into modular systems hosted on multiple spacecraft.[24] These new concepts, when proven, might replace (or, at a minimum, supplement) our current architectural approach of small numbers of large, expensive spacecraft—the space equivalent of less-complex life forms that achieve resiliency through their ubiquitousness.

Air Force Chief of Staff General Norton Schwartz recently commented that "If a defensible [space] posture can be achieved not only by hardening and improving maneuverability of large, complex satellites, but also by smaller, simpler satellites, then we might emphasize further development of some less exquisite augmentation systems. With flattening budgets and likely declining purchasing power, these sorts of tradeoffs, while difficult, must be considered."[25] The advance of small satellite technology is rising to meet the challenge—and smaller is better—for reasons well-grounded in engineering, acquisition, and operational art.

Notes:

[1] Dr. Peter M. Wegner, "Year in Review: Operationally Responsive Space Office," *SatMagazine* 6, no. 8 (December 2008): 46, http://www.satmagazine.com/2008/SatMag_Dec08.pdf.

[2] Wikipedia online entry, "Satisficing," http://en.wikipedia.org/wiki/Satisficing. "Satisficing (a portmanteau of satisfy and suffice) is a decision-making strategy that attempts to meet criteria for adequacy, rather than to identify an optimal solution. A satisficing strategy may often be (near) optimal if the costs of the decision-making process itself, such as the cost of obtaining complete information, are considered in the outcome calculus."

[3] For example, the per-unit cost of the Standard Missile-3 (SM-3) used in 2008 to shoot down the malfunctioning USA-93 satellite is roughly $10M a copy. See http://www.deagel.com/Anti-Ballistic-Missiles/Standard-SM-3-Block-IA_a001148009.aspx for additional details.

[4] There are no standard definitions for the terms "microsat," "nanosat," and "picosat" across the greater international aerospace community. A commonly-accepted definition in the US is: microsatellites are satellites with a mass <1000 kg, nanosats < 100 kg, and picosats < 10 kg (with some minor variations along weight boundaries). A small satellite is any satellite encompassed by these definitions. This article uses this classification scheme throughout. An alternative scheme is used by The Aerospace Corporation that differs by one order of magnitude (placing microsatellites within 10-100 kg).

[5] The Tsiolkovsky (or Ideal) Rocket Equation is given by $\Delta V = V_e \ln (m_o/m_1)$, where ΔV is the total change in velocity, V_e is the effective exhaust velocity of the propellant gases, m_o is the initial total mass of the rocket (including propellant), m_1 is the final total mass of the rocket (including payload), and ln indicates the natural logarithm function (the inverse function of the exponential function). The equation is named for the Russian rocket scientist Konstantin Tsiolkovsky who is generally credited for first deriving and publishing the equation in 1903 (see http://en.wikipedia.org/wiki/Rocket_equation for additional background).

[6] Jim Fenwick, "POGO," *Threshold: Pratt & Whitney Rocketdyne's engineering journal of power technology*, Spring 1992, available at http://www.engineeringatboeing.com/articles/pogo.htm.

[7] Excessive structural stiffness may negatively impact the shock survivability of individual spacecraft components—there is an engineering trade involved; however, modern microelectronics are capable of withstanding severe loads.

[8] An additional complication with calculation of spacecraft first fundamental frequency is that most large satellites today are either liquid-fuelled (creating "slosh" modes that are generally lower in frequency than the unfuelled spacecraft itself) or have fragile appendages (solar arrays or antennas) with low resonant frequencies exhibited even when stowed during launch. While small spacecraft today often lack these subsystems, even if propulsion or deployable structures are added in the future their impact will be mitigated by the same specific strength considerations outlined above.

[9] The engineering purist will note I am conflating static strength and structural stiffness in this analogy, but the two are closely related.

[10] Over the past decade there have been significant advances in the areas of launch vehicle vibration isolation and suppression for small satellites under 1000 kg. In particular, CSA Engineering (manufacturer of the

ESPA ring) has developed simple "add-on" tuning systems for DoD Space Test Program and AFRL payloads; however, these solutions (while quite flexible) are still customized based on specific launch vehicle properties established well before launch.

[11] DoD Space Test Program, *Secondary Payload Planner's Guide For Use On The EELV Secondary Payload Adapter*, July 2006. The ESPA standard specifies a maximum spacecraft mass of 400 pounds (180 kg), total volume of 24 x 28 x 38 inches, and center of gravity offset from the separation plane less than 20 inches (minor variations may be authorized pending additional analysis). An ESPA-compatible spacecraft is best visualized as the size of a dorm room refrigerator.

[12] Secretary of the Air Force to commander, Air Force Space Command, memorandum on ESPA policy, 13 February 2008.

[13] Even the "simple" task of raising the primary payload by 24 inches to insert an ESPA ring has cascading systems engineering impacts that require reworked analyses for venting, aeroacoustic loads, center of gravity/flight dynamics, wiring harnesses, ordnance discretes, etc., for missions where ESPA is added to the flight manifest as an afterthought.

[14] The term "CubeSat" is generally credited to California Polytechnic State University (CalPoly) professor Jordi Puig-Suari who developed the CubeSat technical specification in 1999 along with Stanford professor Bob Twiggs, another pioneer in small satellite development. There are other competing standards including an imperial-unit size (4" x 4" x 4") developed by the Aerospace Corporation for DoD Space Test Program-use on the Space Shuttle, but the CalPoly CubeSat standard is most prevalent today. For additional information see the online Wikipedia entry at http://en.wikipedia.org/wiki/CubeSat

[15] The 1U standard cubesat has been supplemented by 2U (10 cm x 10 cm x 20 cm) and 3U (10 cm x 10 cm x 30 cm) variants. The standard P-POD can hold either three 1U, one 1U and one 2U, or one 3U CubeSat within its internal volume. Efforts are currently underway to develop P-PODs or equivalent standard launchers capable of handling 6U (10 cm x 20 cm x 30 cm) or 12U (20 cm x 20 cm x 30 cm) CubeSats.

[16] The Aerospace Corporation (Richard S. Groom and David A. Hinkley), Aerospace Report No. TOR-2008(1531)-7361, *Potential Uses of CubeSat Technology and Standards in DoD Applications: Part I, Community Survey*, 30 November 2007, 5.

[17] CubeSat Project Website, "Poly Picosatellite Orbital Deployer Mk III Interface Control Document," http://cubesat.org/images/LaunchProviders/mkIII/p-pod%20mk%20iii%20icd.pdf

[18] The "shipping container" analogy for P-PODs was first coined by Mr. Pat Bournes, Program Manager for the National Reconnaissance Office CubeSat Experiments (QbX) program. See http://www.cubesat.org/images/cubesat/presentations/DevelopersWorkshop2009/Bournes-Keynote.pdf for an insightful comparison of CubeSats as compared to the development of commercial shipping standards in the 19th and 20th centuries.

[19] Wikipedia online entry, "CubeSat," http://en.wikipedia.org/wiki/CubeSat.

[20] See http://mstl.atl.calpoly.edu/~bklofas/Presentations/DevelopersWorkshop2009/1_New_Tech_1/3_Voronka-Orbital_Debris.pdf for additional details. The statistical calculations for orbital collisions are complicated by many additional factors; for example, while CubeSat proliferation may eventually contribute to a substantial increase in the total number of orbiting objects, their collision cross-section (a function of satellite volume) is substantially smaller than today's large satellites.

[21] The NASA Marshall FASTSAT satellite, a secondary payload on the STP-S26 mission, is slated to release the second NanoSail-D technology demonstration CubeSat in Summer 2010. The first attempt to launch a NanoSail-D secondary payload failed in 2008 during a SpaceX Falcon 1 launch co-sponsored by NASA and the ORS Office (see http://www.nasa.gov/mission_pages/smallsats/nanosaild.html for additional details). It is interesting to note that orbital lifetime is one negative consequence of the current ESPA standard—ESPASats that maximize the available volume and mass while employing body-mounted solar panels (as compared to deployable arrays) tend to have unusually-high ballistic coefficients resulting in long orbital lifetimes. This fact is spurring the introduction of drag-enhancement devices on these satellites.

[22] Department of Defense, *Strategic Deterrence Joint Operating Concept* (OPR: Director, Policy, Resources and Requirements, US Strategic Command, Offutt AFB, Nebraska, February 2004), 43-44. The author was the original concept writer for this section and penned the verbatim text. As a result of the December 2006 document update (now known as Global Deterrence Joint Operating Concept Version 2.0), the entire section on space capabilities was removed in favor of increased discussion on deterring non-state (terrorist) threats.

[23] Orbital Sciences Corporation, press release dated 18 December 2009, "Orbital Awarded Phase 2 Contract for "System F6" Satellite Program by DARPA," http://www.orbital.com/NewsInfo/release.asp?prid=714.

[24] For an extensive discussion on fractionated spacecraft, see Mr. Naresh Shah and Dr. Owen C. Brown, "Fractionated Satellites: Changing the Future of Risk and Opportunity for Space Systems," HQ AFSPC, *High Frontier* 5, no. 1 (November 2008) 29-36.

[25] Gen Norton A. Schwartz, chief of staff, US Air Force (address, Air Force Association Convention, Orlando, Florida, 18 February 2010).

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Deterrence for Space: Is Operationally Responsive Space Part of the Solution?

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Introduction: The Space Domain and the Need for Deterrence

The space domain, often referred to as "The High Frontier," no longer is a sanctuary outside the reach of foreign intervention. The threat to space systems and their capabilities is broad, ranging from reversible effects such as jamming or blinding, to more destructive means such as anti-satellite weapons. It is now time to take actions for the *sake of space*, and assure its continued contributions across the full spectrum of military operations. Given the criticality of space to not only our military power, but also our economic power, it is time we develop policies and field capabilities to deter future adversaries from attempting to degrade, deny, or destroy space capabilities and services. The asymmetric advantages enabled by space can no longer be assumed and as a result, a new National Security Strategy for space must be forged, one that combines deterrence with basic protection capabilities never before afforded our space systems. Yet, space deterrence is not an "all in" strategy, nor can it reduce the risk of attack to zero.[1] Should aspects of deterrence fail, we must take steps to defend and protect our space systems and the critical global services they provide.

Operationally responsive space (ORS) by definition is "assured space power focused on timely satisfaction of joint force commanders' needs."[2] Dissected further, one key word stands out: *assured* … being sufficiently robust, timely, agile, adaptive, and resilient, to achieve desired outcomes with a high degree of certainty.[3] So while ORS intends to provide operational and tactical support to the joint warfighter, its true value will be the assurance it provides as a credible strategic *deterrent* against space attacks.

As a deterrent, ORS provides access to existing capabilities, or rapid deployment and employment of new capabilities, denying the benefits our adversaries may seek by attacking our space capabilities. Through timely and accurate intelligence, we can work to understand our adversaries' intent and armed with this knowledge, we gain the opportunity to influence their decision-making calculus. Understanding intent, coupled with credible and timely ORS capabilities, can effectively deny or greatly reduce the benefits they seek by attacking the asymmetric advantages enabled by space.

ORS provides a responsiveness that will allow the commander, US Strategic Command (CDR USSTRATCOM), to respond and support our combatant commands real-time and near-term requirements. To support these requirements, ORS consists of three tiers of capabilities: Tier 1, the employment of existing capabilities within minutes to hours; Tier 2, the rapid call-up, launch and deployment of tailored, ready to field capabilities within days to weeks; and finally, Tier 3, the rapid development of a new capability to meet a combatant commander's joint urgent operational need within months to a year.

The Unified Command Plan assigns CDR USSTRATCOM the responsibility for all military space. The space systems under his authority and control provide our warfighters increased speed, precision, and lethality in military operations. In 2007, during an Air Force Association speech in Los Angeles, California, General C. Robert Kehler, commander, Air Force Space Command and former deputy commander, USSTRATCOM, stated that the biggest difference between 25 years ago and today, was that "space today is embedded in combat operations."[4] ORS' strategic deterrent value has the potential to be just as important to future combat operations.

Nuclear and Traditional Deterrence Theory – Misapplication When Applied to Space

For years, deterrence theory centered solely on nuclear deterrence strategies, which relied heavily on threats of punishment and unacceptable losses or mutually assured destruction. These strategies effectively deterred the use of nuclear weapons throughout the Cold War to present day. However, strategies of threatening devastating nuclear retaliation do not apply to space. In fact, a deterrence strategy that includes the threat of punishment (i.e., impose cost) should be just one, if not a limited aspect of deterrence for space.

For almost half a century, nuclear deterrence strategies formed the foundation for the Cold War waged between the US and the former Soviet Union. Both superpowers relied on the threat of nuclear weapons to deter even conventional military actions, for fear of rapid escalation. In its most unlimited form, mutual assured destruction was a key deterrence strategy; a doctrine of military strategy in which a full-scale use of nuclear weapons by two opposing sides would effectively result in the destruction of both the attacker and the defender.[5] While nuclear weapons continue to be a strategic deterrent, the same destructive thought process and strategy is not directly applicable to space.[6]

Today, some theorists focus and apply more punishing or destructive deterrence practices and thinking to the space domain. They view credible deterrence in space as relying upon the threat of punishment against an aggressor; going so far as to suggest that an attack against us could be countered with an attack in kind. One specific definition limits deterrence to an "attempt to persuade an adversary by threat of force (and other measures) not to pursue an undesirable course of action."[7] Another theorist states, "Deterrence can only succeed if the enemy finds the threat of punishment to be believable."[8] These approaches are less likely to deter for space, especially given our dependence upon the domain. For example, destroying an adversary's satellite, especially one in an operational orbit, would create a large debris field, potentially hampering or denying our own ability to access space. Instead, deterrence for space can only succeed if our enemies believe we have credible means of denying the benefits they seek to gain. Space deterrence theory should focus on credible ways and means to deny an enemy the benefits they seek; impose costs on our adversaries (against their most prized assets);[9] and encourage their restraint.

A New Focus of Deterrence

What does deterrence look like in the 21st century? The US has not yet figured that out, said Marine Corps General James Cartwright, vice chairman of the Joint Chiefs of Staff. "You need something that deters a conflict, and you need more choices than just nuclear.

~ Sandra I. Erwin, *Future of War—How the Game is Changing*

… Our deterrence strategy no longer rests primarily on the grim premise of inflicting devastating consequences on potential foes…. ~ US National Security Strategy, 2006

In fact, the US does have new and plausible thoughts on 21st century deterrence. Authored under the leadership of General Cartwright, then commander of USSTRATCOM, and signed out in December 2006, the Deterrence Operations Joint Operating Concept (DO-JOC) is the Department of Defense's (DoD) latest view on deterrence. This approach extends beyond traditional nuclear deterrence theory, which dates back to the heralded days of Strategic Air Command.

The DO-JOC states that the purpose or objective of deterrence operations is to "convince adversaries not to take actions that threaten US vital interests by means of decisive influence over their decision-making."[10] In order to influence our adversaries' decision-making calculus, it focuses on and integrates three key elements: Deny the benefits the adversary seeks; impose costs the adversary fears; and encourage adversary restraint (by convincing them that restraint will result in an acceptable outcome).[11] Of these three elements, denying the benefit should be our focus when fielding new ORS capabilities. Deterrence today can only succeed if our adversaries find ORS credible enough to enable military operations even in a contested environment.

Deny the Benefits—ORS Tier 1 and Tier 2 Examples

People's Liberation Army's (PLA) view of space: Space shifting from enabler to key battleground. Space characterized as important because it contributes to information dominance; space now described as important in its own right….many in the PLA see space as a likely future arena for conflict.

~ Space and PRC National Security,' Dean Cheng, China specialist, The Heritage Foundation, 8 October 2008.[12]

The purpose to benefit denial is to convince an adversary that their intent will not be achieved, or have little to no value. Today, our ability to field ORS capabilities is minimal at best, and unconvincing as a credible deterrent. Instead, our adversaries likely perceive great benefit in attempting to deny the US' space capabilities. These benefits, also referred to as "vulnerabilities gaps,"[13] are reasons why we must pursue ORS with an increased sense of urgency. However, for benefit denial to be viewed as a credible deterrent, the Eisenhower Center for Space and Defense Study states "our adversaries (must) perceive that the US will retain superior warfighting capability even after an attack."[14]

The space and cyberspace domains are increasingly important to how current and future wars will be fought and won. As recently as 4 November 2009, the People's Republic of China's (PRC) top Air Force Commander, Xu Qiliang, called the militarization of space an "historical inevitability."[15] This statement came on the heels of an historic visit to USSTRATCOM by General Xu Chihou, one of two vice chairmen of the PRC's Central Military Commission. During this visit, General Kevin P. Chilton encouraged increased cooperation and comprehensive bilateral relationships between the two space-faring nations.[16] Statements from Qiliang and actions such as the 2007 anti-satellite test highlight a growing disconnect between the PRC's actions and stated policies, increasing concern amongst US leaders and lending credence to the need for new deterrence practices.

Moving forward, to be a true deterrent, ORS must also win the race to space in both the speed and cost of fielding capability versus our adversaries' attempts to counter, destroy, or deny them. Two examples highlight how ORS could play a credible role in deterring adverse actions against our space capabilities: (1) International cooperation and partnerships through shared space capabilities (Tier 1) and (2) the ability to rapidly augment or replace some aspect of existing on-orbit ISR assets in low Earth orbit (Tier 2). Tier 1 and Two ORS capabilities can be deployed and employed rapidly, within hours to days. The cost for Tier 1 includes implementing new concept of operations for deployed on-orbit systems, or the rapid, low cost launch and deployment of systems intended to augment existing systems for Tier 2.

International Cooperation and Space Partnerships - Space Situational Awareness for Increased Probability of Detection and Attribution (ORS Tier 1):

In today's security environment, we rely upon coalition support for military actions around the world. To support this, we engage in joint exercises, purchase compatible weapon systems, and ensure interoperability of military systems required for basic functions such as navigation, ground radio communications, and aerial refueling. However, to date, these same ideas of aggregating coalition capabilities through commonality and interoperability have limited translation to space. Instead, the US and many of our allies operate independent space systems, with limited interaction, data sharing or capability to "integrate and synchronize" in times of crisis. Possibilities for shared capabilities include communications, navigation and space situational awareness (SSA). With our allies continuing to develop and expand their space capabilities, the timing is right to strengthen international cooperation and partnerships with them for the shared use of space during times of peace and conflict.

One area of greatest concern to the US has been SSA. For years, service and joint commanders have stated that SSA is their highest priority need, serving as the foundation for superiority in space. New SSA capabilities such as the Space-Based Surveillance System have yet to be fielded. Concurrently, the global space surveillance network (SSN), made up of legacy systems designed to detect and track satellites and missiles launched from the former Soviet Union, continues to age, requires major refurbishment, and does not provide the capabilities needed in the present threat environment. Even with today's SSA capabilities, significant coverage gaps exist within the US network. Regions of the world outside the western hemisphere, not covered by the SSN, provide significant opportunities to interfere with or attack our satellites, without fear of detection or attribution. For this reason alone, Tier 1 partnerships with allies to expand our coverage beyond current capabilities provide immediate benefit towards surveillance of space. Agreements to share SSA data, especially in regions with limited or no SSA coverage, would increase our ability to detect a possible attack, but more importantly, attribute it back to the aggressor.

Access to allied SSA capabilities and data from outside our surveillance visibility begins to close US coverage gaps. By increasing our detection capability, we reduce the likelihood of an unattributed attack. This likely would deter an adversary from taking actions on-orbit, or even attacks utilizing ground-based capabilities. Through proper agreements, there's great value in adding these capabilities into routine, day-to-day operations. Yet, there may be legitimate reasons why we might only access some allied capabilities during increased tensions or time of conflict, viewing them as a "ready reserve" only. By doing so, and communicating our intent to tap into non-specified capabilities, we maintain a valid surge capability, while limiting our adversary's ability to develop tactics, techniques or procedures to counter these non-standard modes of operation. Stating and exercising these reserve modes would demonstrate their credibility, aiding towards denying the benefit of military space actions outside the range of the US SSN. With the appropriate agreements, operational concepts and data feeds in place, routine modes would provide continuous 24/7 support, while ready reserve modes would allow our joint commanders flexibility in accessing additional SSA capability within minutes, resulting in a true on-orbit ORS Tier 1 capability.

Rapid Augmentation of On-Orbit Intelligence, Surveillance and Reconnaissance (ORS Tier 2):

The US' need for information and situational awareness continues to increase through all phases of military operations, as witnessed in the current conflicts in both Iraq and Afghanistan. For example, over the past several years, the Air Force surged unmanned aerial system (UAS) coverage within Iraq and Afghanistan, increasing overhead air persistence and providing near-continuous situational awareness to troops on the ground. Counter to this, overhead reconnaissance provided by space has not been this responsive. The high cost to access space, both in launch vehicles and the exquisite nature of the systems have been contributing factors. This is not to say that satellite reconnaissance has not played a vital role in these conflicts. Nor should it suggest that we abandon these systems for less exquisite, less capable intelligence, surveillance, and reconnaissance (ISR) platforms. Exquisite systems and their capabilities play a key role in our national security, enabling the strategic decision-making of our senior government and military leadership. However, due to their low-density nature yet high-demand information services, they provide an attractive target for a future adversary.

Space-based collection systems deliver key strategic indications and warning of denied areas. Future adversaries will likely seek to deny the US access and visibility of their movement, even with the limited persistence provided by our low-density, high-demand space systems. Early indications and warning, especially of sites known to possess space negation capabilities, will be critical during Phase 0 of joint operations, the shaping phase, as we attempt to prevent or prepare for a conflict.[17] The actual denial of space capabilities may serve as the transition trigger to Phase 1 of joint operations, as we struggle to gather information and gain the necessary situational awareness required to define the crisis. The time frame for Phase 1 may be limited, likely occurring over just a few short weeks. Our ability to observe, orient, decide, and act on the situation could be greatly hampered if early indications and warning is denied during these critical early days of a potential conflict. This end-state provides great benefit to a potential adversary.

Denial of our ISR may occur through several means: Either purposeful, reversible interference such as blinding or a more catastrophic, direct-kinetic attack against an on-orbit system. Regardless of the means, one of the adversary's goals would be to deny the US full-spectrum electromagnetic "visibility" to denied areas. Yet, a credible Tier 2 ORS capability to rapidly access, augment or replace some aspects of ISR would deny this benefit. This sort of rapid capability, especially in a small satellite system, will not provide all the exquisite capabilities afforded by our national systems. However, if credible, it should provide military planners the responsiveness necessary for situational awareness and intelligence to define the crisis, effectively denying the adversary the benefits they desire in the early stages of a conflict. Further, by reducing the cost of Tier 2 launch and space systems to just tens of millions of dollars, we have the potential to launch numerous ISR systems in a very short period. In this case we quickly move from high-demand, low-density overhead space reconnaissances to a relatively large ISR constellation with high revisit coverage and increased space-based persistence. In short, ORS would provide surge or swarming global coverage, with increased access and revisit to regions of interest. While the adversary seeks to limit or deny our access, their actions would instead result in ORS denying these benefits through increased persistence that did not previously exist. If proven credible, both in our ability to rapidly launch and access space, and to provide decision makers useful intelligence of the situation, ORS Tier 2 augmentation of ISR provides a key deterrent against attacks.

Tier 1 SSA cooperation and Tier 2 ISR augmentation are just two examples of how ORS could act as a deterrent. Yet, deterrence for space can and should extend beyond the space domain … high altitude, long duration systems, UAS's, and new aircraft capabilities could be used to augment, or replace on a limited basis, capabilities provided by space. These cross-domain capabilities likely will not enable the same speed, precision, and lethality to military operations afforded by their space-based equivalents. Yet they would provide a degree of mission assurance, enabling the US to "fight through" a denied period until full space capabilities could be restored. In fact, if our adversaries are convinced that the US can "fight through" disruptions in space, deterrence will be enhanced.[18] Ultimately, survivability of space systems to deliver the enabling capabilities currently through space operations is critical to credibly denying benefits to the adversary.

Deterrence is not the sole answer to preventing attacks. Yet, some believe the DoD seeks only to deter, not protect space assets. One such article claims, "Pentagon planners are looking toward deterrence instead of protection to safeguard critical services provided by space assets in times of peace, crisis, and war."[19] AFSPC and the National Reconnaissance Office have taken initial steps to protect future space systems, with active and passive defenses offering deterrence value as well.[20]

Deny the Benefits—"To Protect and Continue Service"

*Now about a week ago I was sitting with our new chief (General Norton A. Schwartz), and I told him I get the same question over and over. I get this question when I testify, I get this question when I get out in public audiences like this, and the question always goes, actually there are two questions. First question is, are we too reliant on space? And the second question is, what happens if we lose space capabilities? And to the first, I say no we're not too reliant on space, much like our reliance on airpower, it shapes the way America fights. Space shapes the way America fights. And we must continue to have that kind of capability to continue to fight the way we do, which is really the answer to the second question—what happens if we lose it? Well I believe it creates a time warp in the opposite direction, you don't go forward in time, you go backwards in time. We get **slower**, our actions are **less precise**.* ~ General C. Robert Kehler[21]

Offices such as the Space Protection Program, a joint program between the National Reconnaissance Office and AFSPC, are important to current and future space systems.[22] Yet some argue that protection will be too expensive or will likely fail. From 1957 through 2007 the US invested nearly one and a half trillion dollars in space.[23] In 2008 alone, the US spent nearly $43 billion across the National Aeronautic Space Administration (NASA), the DoD and other government organizations.[24] These significant investments in space highlight how much the US stands to lose. To put this in perspective, according to newspaper reports in 2008, Pentagon officials estimated the cost to shoot down the failed US spy satellite ranged anywhere from $30 million and $60 million dollars, with the missile alone costing approximately $10 million.[25, 26] Compare this to a single reconnaissance satellite in low Earth orbit that likely tops $1 billion. This example alone highlights the need to protect space. We must take immediate and prudent steps to protect our space systems to assure basic space-based services to users worldwide.

It is hard to imagine military operations without the position and timing information provided by the NAVSTAR Global Positioning System. Or, the intelligence and situational awareness provided by nearly 50 UAS combat air patrols, remotely controlled through communications satellites from Creech AFB, Nevada. As stated by General Kehler during his 2008 AFA speech, without space, we are slower and less precise in our military operations.[27] In fact, roll back the calendar ten, fifteen, even twenty years, and previous tactics, techniques, and procedures used by military forces in those timeframes may not even be possible today. Integrating space has changed how we execute military operations, from the delivery of munitions, to communications with deployed troops, to basic navigation. This lends more credence as to why protected space capabilities, basic mission assurance for key warfighting functions, and minimizing or eliminating vulnerabilities are long overdue and an absolute necessity moving forward.

History does lend examples of how vulnerabilities can be viewed as an instigator to action. In his 1954 RAND study, "Selection and Use of Strategic Air Bases," Albert Wohlstetter concluded that our overseas, nuclear-capable bomber deterrent was extremely susceptible to attack. In fact, instead of being a deterrent to war, because of their proximity to the enemy, it became a magnet for a potential first-strike. At the time, a first-strike had the potential of eliminating much of America's deterrent force, leaving the former Soviet Union with a capable second-strike option and a nuclear victory. As a result, based on Wohlstetter's recommendation, we dispersed and hardened our nuclear capabilities and invested heavily in early warning capabilities to increase the survivability of our force. Bomber forces were dispersed by pulling them back to nearly 30 US-based hardened locations with increased defenses for early warning and protection.[28] This scenario is especially relevant to today's space capabilities. Our dependence upon space across the range of military operations is similar to our forward deployed bomber force of the 1950s. The vulnerabilities of both invite an enemy strategic planner to exploit these weaknesses. Increased hardening, protection, and dispersal should play a similar role in minimizing vulnerabilities in space.

Impose Costs and Encourage Restraint—Completing Deterrence

This approach to a deterrence strategy, while focused primarily on denying benefits, must also consider means to impose costs and encourage restraint across a broad spectrum of potential adversaries. This integrated approach to deny, impose, and encourage, provides a cumulative effect to achieve a full spectrum deterrence strategy. Deterrence will be adversary dependent. No single action or capability, including ORS, will have the same deterrent effect on each potential adversary.

The US will use credible cross-domain capabilities in air, sea, and possibly land or cyber, to impose costs on an adversary.[29] Examples could include sea or bomber-launched cruise missiles positioned in or near the region, or a future prompt global strike capability.[30] In the end, our most credible means to impose costs will consist of cross-domain capabilities that threaten the most important adversary assets.

While conventional weapon systems play a role in this deterrence framework, encouraging restraint is likely best accomplished through diplomatic measures. The Outer Space Treaty signed in 1967 continues to serve as the basis for international space law.[31] Forty-three years later, an updated Outer Space Treaty is in order. Additionally, establishing other "codes of conduct" for the peaceful use of space may enhance security and maintain stability within the international space community. These steps would broaden the international community committed to the peaceful use of space, creating a more coordinated international diplomatic response to an attack. Yet given this, treaties and codes will be difficult to monitor, verify or enforce. In the event of an attack, especially a non-kinetic attack, attribution back to the perpetrating nation will be difficult to detect, and even harder to prove to the international community. For these reasons, encouraging restraint through pure diplomatic measures, is a legitimate component and will aid in deterrence,[32] but is far less likely to protect or deter attacks on its own.

Summary

ORS provides clear benefits towards deterrence for space. Without effective Tier 1 and Tier 2 capabilities to deter attacks, and protect our space capabilities, our adversaries will view space capabilities as vulnerabilities worth exploiting. By doing so, they could gain early offensive and defensive advantages in a conflict, while greatly affecting our ability to operate. ORS capabilities coupled with a deterrence strategy to deny benefits, impose costs and encourage restraint will maintain our ability to rapidly access space and provide continuous space capabilities during the full spectrum of military operations.

Beyond ORS, deterrence will require a cross-domain approach, with non-space capabilities providing key deterrent value, both in denying benefits and imposing costs. In addition to deterrence through military elements of national power, diplomatic measures should also be explored and undertaken where appropriate. Agreements with other nations would allow access to additional space capabilities and critical data, increasing the time-critical information available to senior decision makers and military commanders. If deterrence does fail and space becomes a contested and denied environment, adequate mission assurance of our basic space capabilities must allow the US and allies to "fight through" the degradation until full space capabilities are restored.

The US has invested nearly $1.5 trillion in space over the last 50 years. The US stands to lose the most military and economic power without it. We must take necessary steps to deter, defend, and protect space capabilities. It is an investment we must undertake.

Notes:

[1] Ambassador Roger G. Harrison, et al., *Space Deterrence–The Delicate Balance of Risk*, Eisenhower Center for Space and Defense Studies, 2009, 4.

[2] Gordon England, deputy secretary of defense, memorandum, 9 July 2007.

[3] Briefing, subject: Operationally Responsive Space, August 2009.

[4] General C. Robert Kehler, "Air Force Association Speech," (address, Air Force Association, Los Angeles, CA, 16 November 2007).

[5] Fact-index, subject: Mutually Assured Destruction; http://www.fact-index.com/m/mu/mutual_assured_destruction_1.html.

[6] Harrison, et al., *Space Deterrence*, 10.

[7] John B. Sheldon, PhD, "Space Power and Deterrence: Are We Serious?", George C. Marshall Policy Outlook, November 2008, 1.

[8] Robert Butterworth, "Fight for Space Assets, Don't Just Deter," George C. Marshall Policy Outlook, November 2008, November 2008, 1.

[9] Harrison, et al., *Space Deterrence*, 7.

[10] Department of Defense, *Deterrence Operations Joint Operating Concept (DO-JOC)*, version 2.0, December 2006, 3.

[11] Briefing, United States Strategic Command/J5, subject: Deterrence, 2007.

[12] Dean Cheng, "Space and PRC National Security," 8 October 2008.

[13] Harrison, et al., *Space Deterrence*, 11.

[14] Ibid, 11.

[15] "China Chief Says Space Arms Inevitable," Agence France press, 2 November 2009.

[16] "Chinese military delegation visits STRATCOM," US Strategic Command Public Affairs, 28 October 2009.

[17] Joint Publication 5-0, Joint Operation Planning, 26 December 2006.

[18] Harrison, et al., *Space Deterrence*, 24.

[19] Robert Butterworth, "Fight for Space Assets, don't Just Deter," November 2008, 1

[20] *DO-JOC*, 37.

[21] General C. Robert Kehler, "Air Force Space Command: Not Business as Usual," (address, Air Force Association, 24th Annual Air and Space Conference and Technology Exposition, Washington DC, 16 September 2009).

[22] HR 1585: National Defense Authorization Act for Fiscal Year 2008, 275.

[23] Michael Krepon and Samuel Black, "Space Security or Anti-satellite Weapons?," Stimson, Space Security Project, May 2009, 12.

[24] "Military Space Almanac 2009," *Air Force Magazine*, Journal of the Air Force Association, August 2009, 54.

[25] "Dead Satellite Shootdown Could Happen Wednesday," *CBS News*, Washington, http://kdka.com/national/Pentagon.wayward.satellite.2.657870.html.

[26] Jason Mick, "Satellite Shootdown Window Opens at 10:30PM Tonight," *Dailytech*, 20 February 2008, http://www.dailytech.com/Satellite+Shootdown+Window+Opens+at+1030PM+Tonight/article10783.htm.

[27] Ibid.

[28] Albert Wohlstetter, et. al, *Selection and Use of Strategic Air Bases*, RAND Study #R-266, Wohlstetter, April 1954.

[29] *DO-JOC*, 37.

[30] Harrison, et al., *Space Deterrence*, 14.

[31] Department of State, Outer Space Treaty of 1967, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, http://www.state.gov/www/global/arms/treaties/space1.html.

[32] Harrison, et al., *Space Deterrence*, 10.

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You Say You Want a Revolution: Will ORS Spark Innovation in DoD Overhead ISR?

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"The time has come," the Walrus said,
"To talk of many things:
Of shoes—and ships—and sealing-wax—
Of cabbages—and kings— …"[1] ~ Lewis Carroll, 1872

The US Department of Defense (DoD) is presently hesitating at a key decision point regarding the evolution of space technology and its associated command and control. A clear and purposeful decision, or lack thereof, will either lead to increasingly assured space-superiority and strengthened national security or a decrease in US relevancy in space and a greater likelihood of "strategic surprise" in the next conventional war.

The Current Situation

… we know from history that every medium—air, land, and sea—has seen conflict … space will be no different.… Thus far the US has not yet taken the steps necessary to develop the needed capabilities to maintain and ensure continuing superiority.[2] ~ Space Commission, 2001

Since the beginning of the space age, the US has largely enjoyed preeminence in space capabilities. Today the national security of the US depends heavily upon continued use of our national and civil space assets.[3] Since our space systems were designed in the latter half of the 20th century using technology available at that time they were naturally built with inherent system "flaws" from that time—these include the fact that they are few in number, extremely expensive, and essentially defenseless. In general, a system designed with these characteristics is acceptable when no threat to it exists. However, the realities of the 21st century have changed the calculus.[4] If space systems were designed from scratch today using modern technology and an acknowledgement of the current threats, the satellites and constellations would have very different characteristics. The same is true for the ground-based architectural elements that support them. This is the main thesis of the operationally responsive space (ORS) movement.

The reasons the US has not already started a deliberate reformation of our current space systems are at least threefold; (1) Many persons are not convinced of the need to change, (2) thorough change to most of the space technology base within the DoD (or any large enterprise) is a daunting task and it is difficult to know where to begin, and (3) bureaucratic stalling, indecision, and a failure to embrace change always hampers revolutionary ideas. The first of these factors is slowly improving because the need for change is becoming evident due to the rapidly developing anti-satellite capabilities of potentially hostile nations. The second reason, facts of life related to equipment replacement, is also being addressed as new systems are developed. Part of the ORS concept refers to the goal of faster infusion of technology, streamlined requirements, and expedited fielding processes. Perhaps this will serve as a catalyst for changing the direction of the US space acquisition juggernaut. That may occur, but a complementary revolution is required, not just incremental improvements. The final reason, though all too often a difficult reality, is the kind of challenge often overcome by forward-thinking airmen, and will be the focus of the following example.

An Opportunity for Revolution

The DoD has an opportunity to recognize and embrace a coming revolution in the delivery of space-based capabilities to warfighters, but tough decisions must be made quickly. The current controversial decisions center on the efficient implementation of TacSat-3 and ORS-1; both of which could become the first operational ORS satellites before the end of 2010. At present the detailed command and control architectures for implementation of these systems are a subject of great debate and thus remain undefined. The debate boils down to a choice between doing business as usual, failing to make any decision at all, or truly blazing a new trail.

Background

The possible transition of TacSat-3 to operations will illustrate this point.[5] In November 2008, at the request of the commander of US Strategic Command (USSTRATCOM), a joint team lead by Air Force Space Command began formal planning for the possible transition of TacSat-3 to become a space-based tactical surveillance and reconnaissance system in direct support of combatant commands (COCOM). The team has evaluated the satellite, created the appropriate follow-on architecture with associated cost estimates, and identified a source for funding beginning in May 2010. Feedback on the performance of this system has been favorable and the team is planning for a final transition decision. If this option is pursued the handover would occur at the end of the Air Force Research Laboratory testing phase scheduled through 19 May 2010. TacSat-3 could thus become the first USSTRATCOM- and US Air Force-owned satellite dedicated to delivering tactical intelligence, surveillance, and reconnaissance (ISR) in direct support of the geographic COCOMs.[6] As such, the systems and supporting architectures would be separate and distinct from the systems owned and operated by the National Reconnaissance Office and other national-level agencies.

Architectural Pathfinder

The planning for TacSat-3 follow-on operations has served as a pathfinder for setting-up the tasking and dissemination architectural elements for ORS-1 and similar ORS systems that may come. The challenging question is—will the mechanisms put into place be streamlined and support the tactical warfighter in a way consistent with the greatest potential of emerging technology; or will the architectures become mired in bureaucracy to the point that most of the advantages are lost?

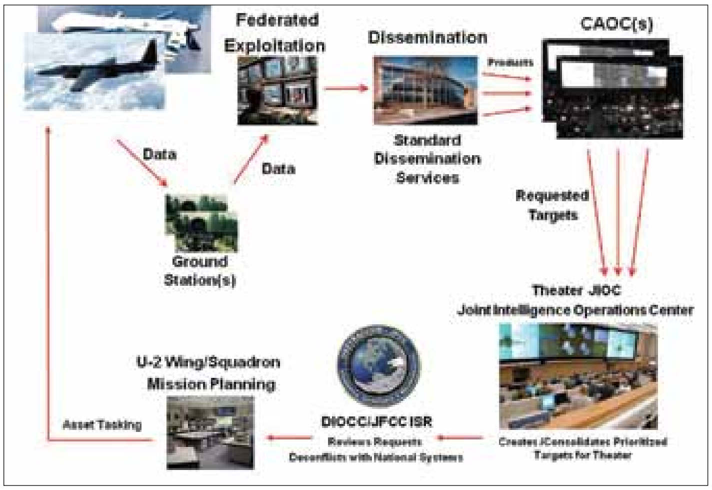

Figure 1. Simplified US Air Force Airborne ISR architecture.

The most expedient and effective way to operationalize a USSTRATCOM-owned space-based ISR asset would be to extend the airborne model to include the necessary players. Since airborne ISR uses the most tactically-focused ISR architecture we currently own this would ensure the most tactical support possible at present. Figure 1 shows a simplified architecture for airborne ISR. In this case the systems are 'organic' assets for the COCOM (or at least the theater) and follow a tasking process that ensures the asset is used primarily for the tactical warfighter. A deconfliction step with national systems is accomplished at the theater Joint Intelligence Operations Center (or in some cases at the joint force combatant commander for ISR in DC). In this architecture all authorities are in place for efficient command and control and deconfliction and optimization between other airborne ISR assets and national systems. Even though tradeoffs often occur between taskings during this coordination step, the COCOM always retains primacy for use of the ISR assets.

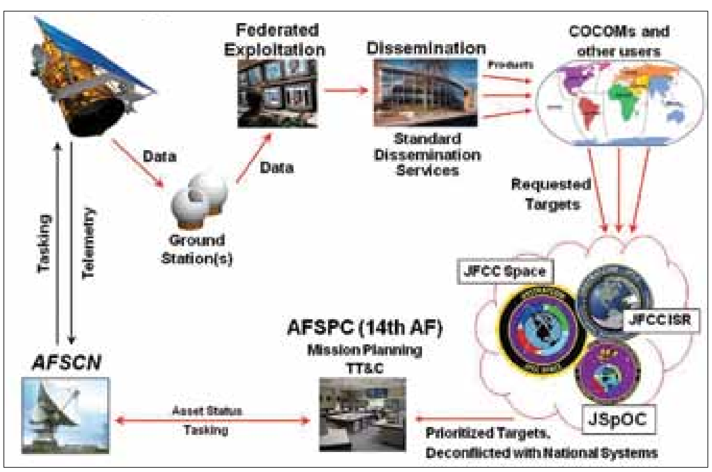

Figure 2. Proposed USSTRATCOM-owned space-based ISR architecture.

Figure 2 illustrates how a USSTRATCOM-operated space-based ISR system could function similarly to airborne ISR. If the intent is to use the satellite to the maximum extent as a tactical asset supporting the COCOMs one need only replace the combined air operations centers (CAOCs), joint intelligence operations center, and operational squadrons with more CAOCs (representing multiple COCOMs because a satellite overflies them all), Joint Functional Component Command (JFCC) ISR, and the JFCC Space/14th Air Force operational squadrons. In doing so the satellite appears to the COCOMs as an organic asset for the time it is over their area or responsibility, JFCC ISR still performs the deconfliction role with national systems, and JFCC Space operates the satellite via the assigned operational squadrons.

In the figure 2 architecture JFCC Space holds *collection operations management* authority and JFCC ISR holds *collection requirements management* authority (unless otherwise delegated by JFCC Space).[7] It is important to note the relationship between these two authorities. The joint force commander collection manager prioritizes collection requirements and recommends the appropriate asset to be assigned to collect against a particular target. The collection manager, in coordination with the operations directorate, forwards collection requirements to the component commander exercising operational and tactical control over the theater reconnaissance and surveillance assets. A mission tasking order is then sent to the unit responsible for the accomplishment of the collection operations. This unit makes the final choice of specific platforms, equipment, and personnel based on such operational considerations such as maintenance schedules, training, and experience. The effective conduct of these two roles will become increasingly important as additional space-based ISR assets are assigned to JFCC Space.

A problem with the above architectural suggestion is that it is currently notional—all the affected agencies have yet to agree. The issue so far is not disagreement between the national agencies and the Air Force regarding who should "own" the satellite. The current problem is that for more than a year we have been reviewing all the possible incarnations of the command and control and system elements for this architecture and this is putting the successful employment of these systems at risk. Making bold decisions now and moving out with purpose is what is required. A clear choice here with a comprehensive DoD endorsement would be a first step toward the realization of the full potential of operationally responsive space ideas.

Figure 3. The "Hyper-tactical" mode for TacSat-3.

"Hyper-Tactical" Operations

The preceding paragraphs refer to architecture and command and control possibilities for the "routine mode" for satellites which can fully support strategic, operational, or tactical needs. However, TacSat-3 was designed with an additional capability which could be referred to as a "hyper-tactical" mode, that is the ability to re-task, process data on-board, and downlink a product to users all in one overhead pass. Figure 3 shows a high-level view of how that capability functions.

This type of capability in a constellation, or multiple constellations, of satellites would constitute an even greater revolutionary leap in tactical support from space-based ISR than previously discussed. In this case, satellites would essentially be used as airborne ISR assets that simply "fly higher." If one wanted to increase the focus on support to the tactical warfighter, fully implementing a "hyper-tactical" mode on small responsive space satellites could be an appealing approach for future systems. It remains to be seen, however, if warfighter needs, technical capabilities, and funding all point toward the maturation of this capability.

Conclusion

The DoD is in the beginning stages of a revolution in technology that could exceed the impact of the birth of airpower. Effectively applied responsive space concepts—in the form of numerous small spacecraft which rapidly incorporate emerging technology and are tied into responsive architectures—would deliver assured capabilities for combatant commanders and improved strategic deterrence for the nation. However, bold and decisive steps must be taken soon.

A first step in the right direction would be to seize the opportunity to revolutionize the way space-based ISR supports warfighters. Our activities with respect to space-based ISR should be pursued with the same vigor with which the Air Force has recently focused on increasing airborne ISR. We must act quickly, we must hold the line with respect to the simplicity of the systems, we must ensure rapid and direct support to tactical warfighters, and we must fully leverage the technology available. If we do so we may very well succeed in jumpstarting the ORS revolution in space.

Notes:

[1] Lewis Carroll, "Through the Looking-Glass and What Alice Found There," 1872, note: the quote references the point at which the Walrus begins to reveal the fact that the Oyster's doom is impending.

[2] Commission to Assess US National Security Space Managament and Organization," also known as "The Rumsfeld Commission," 11 January 2001, para VII, 99, http://www.dod.gov/pubs/space20010111.html

[3] Ibid., VII page 100

[4] Les Doggrell, "The Reconstitution Imperative," *Air and Space Power Journal*, (Winter 2008), http://www.airpower.maxwell.af.mil/airchronicles/apj/apj08/win08/doggrell.html.

[5] TacSat-3 is an AFRL demonstration satellite launched in May 2009 that is equipped with hyperspectral and visible light sensors, on-board image processing software, autonomous flight software, and ocean data telemetry sensors. The satellite is also capable of routine and tactical operations modes; the latter enabling tasking and data download during a single overhead pass. With respect to future space HSI capabilities, the DoD may pursue follow-on experimentation or operational systems with HSI technology. The DoD will use the JCIDS process, in addition to the joint military utility assessment from Artemis, to determine the need and potential benefits of DoD operational HSI systems.

[6] This excludes the CORONA and WS-117L programs of the 1960s because those systems were not dedicated to tactical use. Dwayne A. Day, et al., *Eye In The Sky, The Story of the CORONA Spy Satellites* (Smithsonian Institution, 1998) 145.

[7] Joint Publication 2-01, *Joint and National Intelligence Support to Military Operations*, 2004, III-14.

Lt Col Ryan R. Pendleton (BS, Aerospace Engineering, Auburn University; MS, Human Resource Management, Troy State University; MS, Aerospace Engineering, Air Force Institute of Technology [AFIT]) currently serves as chief, Operationally Responsive Space Integration Branch, ORS Division, Requirements Directorate, Air Force Space Command (AFSPC). He is responsible for the integration of responsive space concepts across AFSPC and the Joint and National Security Space communities. In addition he leads the Operationally Responsive Space-1 Integrated Concept Team and the TacSat-3 Follow-On Capability Team. Prior to arriving at AFSPC in 2007 he served three years as an air attaché at the US Embassy in Paris, France. He was commissioned through ROTC at Auburn University in 1991 and initially served in a number of operational intelligence roles. His focus was on mission planning at the squadron-level but he also led intelligence support at the numbered air force level and executed numerous joint/multinational operations and exercises. After a brief assignment to the National Air and Space Intelligence Center he was selected to attend AFIT. He then served as a developmental engineer designing weapons guidance systems at the Air Force Research Laboratory Munitions Directorate, Eglin AFB, Florida. While serving as a volunteer on the Air Force Scientific Advisory Board, contributed scientific expertise to the Secretary of the Air Force directly supporting studies on effectiveness and survivability of space-based assets.

Maintaining Test Rigor and Fidelity for Responsive Space Programs

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The responsive space concept requires the rapid fielding of space assets to support the warfighter. The requisite condensed acquisition cycles necessitate accelerated development and highly compressed testing schedules. Testing is particularly important with space assets since they are required to work perfectly on the first instance of operation because there is currently no feasible method for repair or adjustment once they are launched. Significantly reducing time to plan and execute the testing of space assets while maintaining high fidelity is one of the largest challenges to developing systems necessary for responsive space.

Inherent Challenges to Acquisition of Space Assets

The acquisition of any space system typically involves significant difficulties compared to typical acquisitions due to three main factors: (1) The harsh and extreme environment in which they must operate including solar radiation, lack of oxygen, zero gravity, extreme temperature cycles, and other space debris and radiation; (2) The small number of operational units built for each program. Many are one of a kind and even the largest programs rarely have more then 20 to 30 satellites per constellation; (3) There is no economically feasible method for repairing orbiting space assets so they must work the first and every subsequent time called upon without maintenance or physical intervention.

As a result of these factors space systems generally require much more rigorous and thorough developmental testing than non-space systems. Unfortunately, long and extensive testing is contrary to responsive space goals to accelerate space acquisition cycles to meet urgent Department of Defense (DoD) and combatant commander needs. This schedule compression makes executing rigorous and thorough testing on new space systems especially difficult.

The solution to resolving the challenges of the compressed development schedules of responsive space and meeting the obligatory aggressive acquisition schedules is to standardize the new systems as much as possible, specifically the hardware, software, interfaces, and support equipment. In order to maintain rigorous testing in short space acquisition programs the benefits of this standardization must also be leveraged.[1,2,3] The key to accomplishing high-quality testing in a limited timeframe is to leverage standardized equipment and hardware, software, test strategy, and documentation, and take advantage of opportunities to combine test activities.

Standardizing the Equipment and Hardware

Operationally responsive space (ORS) programs such as ORS-1 are using lessons-learned in the research and development (R&D) space arena to accelerate system acquisition programs. Among these is the strategy to standardize common equipment. This standardization has successfully reduced system acquisition timelines. Testing of these compressed-schedule systems must also leverage standardized equipment in order to proportionately reduce testing timelines. This concept has already been implemented on both R&D ground systems (GS) and space vehicle systems.

Standard Ground System

The Multi-Mission Satellite Operation Center (MMSOC) Ground System Architecture (GSA) is a perfect example of leveraging standardized equipment to shorten GS testing timelines without losing fidelity or test rigor. The MMSOC GSA system was designed as a standard core command and control (C2) system to be used on all future satellites that will be built or fly out of the Space Development and Test Wing (SDTW) at Kirtland AFB, New Mexico or Satellite Operations Center 11 at Schriever AFB, Colorado. The MMSOC GSA Strategic Intent document describes the advantages and efficiencies of such a system.

> The MMSOC GSA will consolidate satellite operations by providing an agile and flexible overarching ground system enterprise. Additionally, a tailorable standard user interface will provide commonality across multiple missions which will minimize cost and time investments. This flexibility and responsiveness is the key enabler to achieve the capability. The MMSOC GSA is designed to support multiple types of satellites. Because the satellites this ground system will operate are varied, it will not be built as an optimized (or stove pipe) system. To enable the MMSOC GSA to have the flexibility to operate many different satellite missions and payloads, internal and external interface standards must be established. These standards will be published for the satellite developers and manufacturers, developers of [Telemetry, Tracking and Command] TT&C tools, and external agencies that will interface with the MMSOC GSA. By establishing, publishing, and applying interface standards the MMSOC GSA will be able to rapidly integrate new satellites, increase capability through hardware and/or software upgrades, and expose and publish data and services to other users... The standard interface will minimize the impact of satellite specific implementation, allow the MMSOC GSA to follow a spiral de-

velopment path, and enable more rapid integration of new or improved capabilities.

The MMSOC GSA will provide a defined standard interface for satellites and external users. With these standard interfaces, the MMSOC GSA is a net-centric satellite operations system, providing rapid integration of new satellites… [and] provides for rapid expansion of system capability through hardware and/or software upgrades. The design of MMSOC GSA enables rapid capability expansion to support joint or interagency operations.

The MMSOC GSA, as an ORS enabler, will follow the ORS procurement process. This process allows for rapid acquisition of systems in order to support warfighter needs.…

The MMSOC vision provides a collaborative environment where warfighters and developers can rapidly and cost-effectively introduce new space capabilities to the fight.

ORS provides the capacity to respond to unexpected loss or degradation of selected capabilities, and to provide timely availability of tailored or new capabilities. Currently, the MMSOC GSA has been designated as a primary satellite operations capability for the ORS satellites and/or payloads. It has been designated as the ground system for ORS Satellite (ORS-1), and Space Test Program Satellite (STPSat)-2."[4]

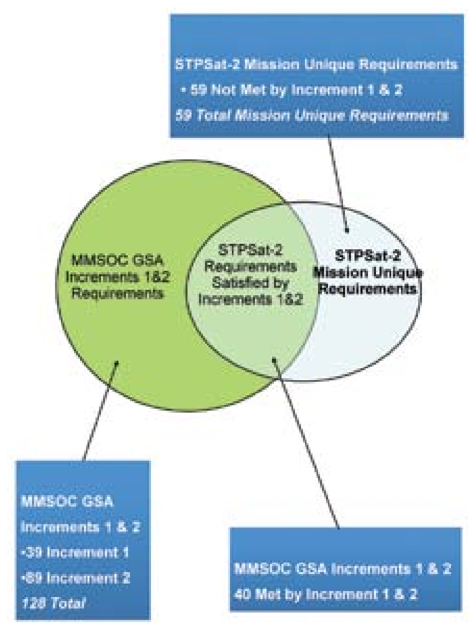
This description emphasizes the concept that use of standardized GS equipment, hardware, software, and interfaces will shorten the development schedule of future satellite programs. The advantages and efficiencies obtained through a common core ground system must also be leveraged by the space test community to reduce testing timelines. This is currently being demonstrated in the testing strategy of both satellite programs identified in the strategic intent document, STPSat-2 and ORS-1.

MMSOC GSA provides the common core ground system for both satellites. The core consists of a majority of the requisite GS hardware and a platform for C2 software, such that new satellite programs could simply develop and install necessary mission unique hardware and software and be ready to launch in a very short time period. Since the core functionalities that are generally common among most satellites are met by the core MMSOC GSA system, new satellite systems can save testing time by referencing the MMSOC GSA test results rather than duplicating them. Since many of the system requirements are met by the core system, the results from previous MMSOC GSA testing can be applied to "buy off" on the mission unique GS requirements.

The STPSat-2 program will be the first satellite to fly on the MMSOC GSA system with ORS-1 to follow. Both programs are being developed in parallel, which afforded the opportunity to directly identify requirements overlap. During the preliminary design review it was shown that of the 99 total STPSat-2 GS requirements (found in the Ground Specification Document),[5] 40 requirements overlapped with MMSOC GSA requirements. This allowed testers to verify 40 STPSat-2 requirements via MMSOC GSA acceptance testing results, leaving only 59 mission unique requirements to be verified through additional STPSat-2 testing. Assuming a relatively even distribution of requirement verification workload, this equates to a reduction in testing effort by over 40 percent, saving the STPSat-2 program over 4,080 contractor man hours (estimate does not include government employee man hours saved). Figure 1 illustrates the requirements overlap between MMSOC GSA and STPSat-2 software. The resulting time and man hours saved could be redirected to focus on accomplishing mission unique hardware and software testing and accelerate the overall test schedule for STPSat-2.

The ORS-1 Program Office and the designated Responsible Test Organization (RTO), SDTW Space Test Operations Squadron, will also leverage MMSOC GSA testing and operations to reduce ORS-1 GS testing similar to that of STPSat-2. ORS-1 will be able to directly reference test results from MMSOC GSA testing to buy off the core capabilities of the GS, allowing ORS-1 testers to focus on the mission unique portion of the ORS-1 GS. Additionally, since ORS-1 will launch after STPSat-2, the successful test results and operational performance of the STPSat-2 can be further leveraged by the ORS-1 RTO to reduce risk and improve confidence. In this regard, ORS-1 potentially can treat MMSOC GSA as government furnished equipment, drastically diminishing the amount of testing required. By leveraging the test results of MMSOC GSA and applying them to other satellite programs the testing schedule can be accelerated without sacrificing testing rigor or fidelity.

In addition to MMSOC GSA, ORS-1 will leverage testing and operations of other portions of the GS that were accom-



# of Requirements	Mission Unique Requirement Areas
11	Data Processing
11	Data Exchange
9	Automatic Retransmission
7	Mission Planning
5	CCSDS
5	Routing Telemetry to SPEX Area
3	Payload Test Center
2	Trending
2	Display
1	Automatic Command to Restart Transmission
1	SPEX Archival Processing
1	Memory Management

Figure 1. MMSOC GSA and STPSat-2 requirements overlap.[6]

plished on prior satellite programs. The ORS-1 satellite will downlink information through ground terminals referred to as common data links (CDL). One of the two ground CDL units that will be used for ORS-1 is currently in use at the National Air and Space Intelligence Center at Wright-Patterson AFB, Ohio for Tactical Satellite-3 (TacSat-3) contacts. The only difference in downlink configuration between ORS-1 and TacSat-3 is the types of files being downloaded. This similarity will reduce the amount of testing required for the CDL ground equipment, since the existing system is already being used operationally. ORS-1 CDL testing will consist of a simple installation and checkout at the site, along with flowing data through the system during an end-to-end test, essentially treating the CDL as an off-the-shelf component that has already been operationally tested. Additionally the use of the CDL was demonstrated prior to TacSat-3 launch by its predecessor TacSat-2. ORS-1 operational use of the CDL will leverage test results from both heritage systems to reduce risk and improve confidence without extending the testing timeline. This process will save ORS-1 numerous testing hours without compromising test rigor.

Standard Spacecraft Bus

Similar strategies can be utilized for spacecraft testing as well. A standard interface vehicle (SIV) or "standard bus" was developed for use on STPSat-2. The objective of the SIV program is to develop multiple space vehicles with a standard payload-to-spacecraft interface that is applicable for all SIV missions. In other words, the concept is to create a common bus that has standard interfaces so that all future Satellite Test Program satellites can be built around the same bus structure. Reusing a standard bus structure with standard interfaces will reduce development time and cost for future STPSats. This use of standard interfaces can be leveraged to reduce testing timelines as well. For example, the bus structure of STPSat-2 (SIV-1), was subjected to qualification testing, which is much more rigorous than prototype testing, and similar to most live fire testing in that it ultimately renders the test article not flight worthy. The second SIV (SIV-2) will serve as the actual spacecraft bus of STPSat-3. Since SIV-2 has an identical physical structure to SIV-1, the results from SIV-1 qualification tests can be reused to qualify SIV-2 without requiring retest. SIV-2 will only have to undergo prototype testing saving time and required to manufacture and test at qualification levels again. The prototype test article will not have to undergo qualification testing so it will still be considered flight worthy and available for use on the operational satellite. This will save both manufacturing and testing man hours that otherwise would have to be duplicated for SIV-2. Leveraging the similarities between SIV-1 and SIV-2 allowed the test schedule for STPSat-3 to be accelerated without reducing test fidelity.

Another way spacecraft bus standardization maximizes test efficiency is by reducing time and effort in test procedure development. The interface test procedures produced during SIV-1 testing can be reused in full with SIV-2 since the interfaces are all standard. Authoring, editing, checking and correcting the test procedures to achieve their final state represent a significant amount of time which does not have to be duplicated as a result of taking advantage of standard interfaces.

Another excellent example of improving test efficiency on space vehicles is found in the ORS-1 and TacSat-3 relationship. The ORS-1 satellite will be built on a bus that is nearly identical to the TacSat-3 bus. ORS-1 will reuse many TacSat-3 features with only minor modifications including: the global positioning system receiver; power control electronics; battery; solar arrays; command and data handling (C&DH) (99.9 percent Heritage); power supply; three axis magnetometer; peak power tracker's; fault management plan; flight software; guidance, navigation, and control (GN&C); hardware status; collection algorithms; collections operations; guidance algorithms; TT&C internal interfaces; C&DH external interfaces; thermal design requirements; temperature design limits; mechanical requirements; and bus structure.[7] All of these similarities have enabled the ORS-1 to be acquired, integrated and tested with unprecedented rapidity. Many of these similarities have also been leveraged to accelerate the testing schedule. The ORS-1 program has leveraged thousands of hours of TacSat-3 efforts since early 2008, including an independent integration and test (I&T) cycle at the Air Force Research Laboratory and stress testing scenarios. Furthermore, TacSat-3 performance requirements that were verified during

Figure 2. The TacSat-3 satellite awaits launch on board a Minotaur 1 rocket, 1 May 2009. The launch from NASA's Wallops Flight Facility, Wallops Island, Virginia.

Equipment and hardware standardization need to be pursued in order to benefit not only development schedules but test schedules as well. One important objective here is to minimize the number of modifications and changes made between future and heritage systems, however minor.

testing could be used on ORS-1. The thermal and mechanical stress analyses performed on TacSat-3 were reused saving testing and preparation time required for such activities. Many of the spacecraft bus test plans and procedures were reused, saving even more time and effort. Testing was further accelerated by reusing many of the test resources used for TacSat-3, such as the FlatSat simulator (a computer system with the satellite flight software installed used to mimic satellite reactions responses and interaction) and the electronic ground system equipment (EGSE). Many of the models and simulations developed for TacSat-3 such as finite element models and Matlab/Simulink models were reused on ORS-1 with only minor modifications. Moreover, ORS was able to use the operational status and performance of TacSat-3 on orbit to reduce risk and increase confidence on components such as: solar array deployment and release mechanisms, launch vehicle separation, power system performance, GN&C pointing modes, bus components, and C&DH software. Finally, ORS-1 used lessons learned from TacSat-3 development and testing to improve efficiency, especially regarding flight software code generation and analysis. All of these methods used to reduce test time while maintaining test rigor prove the concept is feasible. When these concepts are more deliberately applied on future satellite systems, additional cost and schedule savings can be achieved.

Standardization of Test Strategy and Documentation

In addition to standardizing system hardware and test equipment, making documentation standard among multiple systems can also contribute to reducing test duration. Standardizing test strategy shortens the initial test planning process by building off of the planning and lessons learned during earlier programs. ORS-1 used test strategy and processes from earlier missions such as STPSat-2 and TacSat-3, with adjustments based on lessons learned to build a test strategy in a very short period of time. The STPSat-2 program used test plans, test checklists, and even Test Readiness Review slides from previous programs, such as TacSat-3 and Communications/Navigation Outage Forecasting System to expedite the test planning process. Another example is the hypersonic Conventional Strike Missile program, which has reused much of the strategy and documentation from the precursor Defense Advanced Research Projects Agency program called Hypersonic Test Vehicle-2, dramatically shortening the timeline to develop these items from scratch. Documents such as the Preliminary Requirements Document and Environmental Assessment, which are necessary for using the Reagan Test Site and Vandenberg launch facility, can be very extensive and time consuming to author; the ability to leverage these documents from similar, previous programs can save a substantial amount of time and effort. As mentioned previously, ORS-1, STPSat-2 and SIV-2 have all leveraged test plans and procedures to facilitate test efficiency.

In addition to using test documentation from other programs, ORS-1 testers were able to use lessons learned from previous programs to streamline the coordination and staffing process to get signatures and approval of test documentation, which saved months of rework and resubmission.

Combining Test Events

Another method for accelerating testing timelines of satellite programs is to combine test activities with other events. One method of doing this is to combine developmental testing (DT) events with operational testing (OT). This concept has been well established throughout the DoD testing community and is often referred to as integrated testing. This concept was rigorously applied wherever possible within ORS-1 and STPSat-2 by allowing the eventual users to conduct developmental tests and end-to-end tests. However, the unique nature of space acquisition programs makes it difficult to combine DT and OT effectively, especially for R&D programs that may or may not include significant OT efforts. Testing activities can also be combined with training events. STPSat-2 proved this concept by combining testing events such as command and telemetry verification and validation and user acceptance test with training events such as a rehearsal and a readiness event. Additionally, the DT&E test cases that normally would have been conducted by the developing contractors will be conducted by the operators, combining testing and training opportunities. Combining DT activities with other DT events, OT, and training activities can contribute to reducing testing timelines without reducing test fidelity.

Conclusion

Several conclusions can be drawn from the previous examples with regard to future programs. The most significant is that standardization of equipment can significantly decrease testing requirements and should therefore be deliberately sought out and leveraged during test planning wherever possible. In many of the examples discussed, these efficiencies were found after the fact or were a natural result of standardization for rapid development purposes that happen to have application in test. However, to truly maximize the potential efficiencies, these types of testing overlap and reuse, should be meticulously sought out and planned for during initial design and development stages. Equipment and hardware standardization need to be pursued in order to benefit not only development schedules but test schedules as well. One important objective here is to minimize the number of modifications and changes made between future and heritage systems, however minor. The more identical the systems or subsystems are, the more testing results from past programs can be directly applied to verification of future systems. This can lead to eliminating some testing altogether. Unfortunately, even seemingly minor changes and modifications to a component may force the entire subsystem or system to be retested in full, negating the effect of leveraging the heritage system. Along these lines, when modifications are necessary (some almost always are, by definition of a "new system," otherwise it would just be a new instantiation of an old system), efforts should be made to confine the changes to specific subsystems or components to reduce the number of components that must be retested and to reduce the number changes necessary to system level integrated tests. To facilitate this process, the test documentation, such as common/core plans and procedures, should also be modularized as much as possible so testing of each subsystem or component can be separated into sections or test cases such that required modification of one section will not affect other sections or cases.

Implementing these concepts will require the testing community to be involved in the acquisition development process early. They will need to focus on finding opportunities to use testing from heritage systems to streamline their testing strategy. The goal of minimizing test schedules by leveraging heritage system testing should be incorporated in the design process and should be a driving factor in design modification decisions. By actively seeking and planning for test reuse and leveraging, it should be possible to improve testing efficiency even beyond what has been demonstrated in MMSOC, ORS-1, STPSat-2 and SIV-2.

As these systems become more and more standardized it would prove beneficial for test organizations to invest in standardized testing equipment. This would almost certainly appear as an additional cost up front, but will improve test efficiency for future programs that will not have to design develop, pay for and implement the use of new test equipment. Creating a standard set of test equipment such as EGSE, satellite models and simulators, and so forth, would facilitate rapid test planning and execution. This would also alleviate contractors' responsibilities to develop test equipment that is satisfactory to the government and would reduce the amount of proprietary limitations that hamper sharing of test data between programs.

Implementing these methods can significantly reduce testing timelines while maintaining test rigor and fidelity. The basic concepts that have been proven by these programs can be further developed and adapted to increase the level of efficiency yielded through their implementation. If the testing of rapid acquisition space programs is expected to keep pace with the ever decreasing development timelines and resources required by responsive space, then these concepts must be further developed and implemented on future programs.

Notes:

[1] Les Doggrell, "Operationally Responsive Space: A Vision for the Future of Military Space," *Air and Space Power Journal* 20, no. 2 (Summer 2006): 42-49.

[2] Ronald M. Sega and General James E. Cartwright, "Plan for Operationally Responsive Space: A report to Congressional Defense Committees," 17 April 2007.

[3] Les Doggrell, "The Reconstitution Imperative," *Air and Space Power Journal*, 1 December 2008

[4] Maj Nancy D. Baldock and Brig Gen John E. Hyten, "Multi Mission Satellite Operations Center Ground System Architecture Strategic Intent," April 2009.

[5] STPSat-2 Ground Specification Document (GSD), 4 March 2008.

[6] STPSat-2 Preliminary Design Review Presentation, 02_Requirements Review_Venn Diagram and Mapping.pptx.

[7] ORS-1 Space Vehicle Critical Design Review (CDR), presentation, VG_A40-0061_ORS-1_CDR_Vol_3.ppt.

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USAFA Astronautics Capstone Programs—Proving Ground For Future Operationally Responsive Space Leaders

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Introduction

The US Air Force Academy's (USAFA) space operations and astronautical engineering academic programs are comprised of a core course foundation that transitions to a set of courses focusing on astronautical engineering and space operations. The culmination of this four-year academic journey is the year-long senior design capstone course experience. *High Frontier*'s August 2007 volume (vol. 3, no. 4) featured "US Air Force Academy Department of Astronautics Space Programs" that introduced and provided detail of the Academy's space education programs. The capstone course sequences are comprised of three major programs: FalconSAT, FalconLAUNCH, and FalconOPS. All astronautic and space operations majors choose one of these sequences, while cadets pursuing other technical disciplines, the sciences, and management can also enroll in one of these capstones. The cadets from other majors can participate provided they have completed certain prerequisites and are cleared via recommendation from their "home" department and an interview with astronautics department leadership. These capstone courses are not for the faint of heart. Cadets often compare them to picking up a second full-time job on top of all the other demands on cadet time. For example, one cadet in one semester logged more than 400 hours working as a FalconSAT avionics integration and test engineer. An astronautics capstone calls for long and arduous hours in which cadets literally form a company and pursue the design, build, test, and fly aspects of a space system or in planning, scheduling, training for, and executing real world satellite operations.

Figure 1. Illustration of the three capstone sequences.

It is in these capstone programs that the cadets face and solve technical and operational challenges not unlike those they will face as space professionals who will go on to develop, acquire, field, operate, and leverage operationally responsive space systems in the near future. In all our capstones, time is at a distinct premium. The faculty and cadets must achieve major programmatic milestones during a two-semester timeframe encompassing nine months. For FalconSAT satellites are designed and built over three years, this includes completion of engineering modeling and design, qualification testing, and actual assembly, integration, and test of the final space flight vehicle that will carry Space Test Program/Air Force Research Laboratory (AFRL) approved payloads and experiments. For FalconLAUNCH, it is all the steps necessary to design and test a powerful sounding rocket for an April rocket launch to altitudes as high as 300,000 feet that likewise includes Department of Defense approved experiments conducted in flight. FalconOPS faces high tempo satellite operations to accomplish experiments on-orbit. It is not without the challenges of anomalies and their investigation and resolution using an all-cadet crew force. Also included in FalconOPS is the "space-for-all" military training program, which exposes cadets from all majors to satellite operations. Then there's graduation—the equivalent of firing your entire company staff and hiring new employees since only seniors participate in the program and the program's mantle must be passed to a new rising class each year.

Operationally Responsive Space Situations Faced Everyday In USAFA's Space Programs

Before providing specific examples of the operationally responsive space (ORS)-like situations in which our cadets find themselves, this article will highlight the essential tenets of how USAFA ensures the cadets swiftly tackle and solve engineering and operations problems as they move forward on their satellite, rocket, or operational campaign. USAFA does not foster nor tolerate reckless or seat-of-the-pants approaches to space systems and operations designs. Cadets are equipped with the education foundation and a locker room comprised of seven faculty and technical experts to enable them to move swiftly and back their decisions with solid and timely technical analysis and know how. All the capstone endeavors kick off with clear objectives accompanying real Air Force customers armed with requirements, data, and a fervent look in their eyes as they count on the cadets' success to fly their experiment or device in space or on a rocket. The program, in fact, depends upon real customers for the overwhelming majority of its funding.

After receiving their top-level objectives for the year, the cadets are introduced to the "government team" of mentors that is, in fact, USAFA faculty and a small team of experts who have served many years in the space and launch industry. The mentors serve in a dual role as cadet evaluators and leaders, with one or more experts heading each capstone program sub-system team (e.g., avionics, structures, propulsion). The teams are also supported by laboratory technicians (non-commissioned officers and civilians) that assist with machining, electronics, testing, and other infrastructure and support requirements.

Throughout the year, the teams must accomplish quantifiable assessments of a wide variety of engineering and programmatic problems. It may be a simple back-of-the-envelope calculation or a high-fidelity simulation to confirm a design or prove a problem solved. Then, given the "time not on our side" feature of the program, the cadets must complete quick and accurate analyses and come to a conclusion. There is no time for extensive PowerPoint presentations, formation of independent review teams, or establishing sustained working groups. The cadets and their faculty mentors must be agile and responsive as they stay on objective and schedule and answer to the faculty and customers. Often there is a tight launch date facing them driven by a variety of external factors they do not control such as a fleeting few days to get on the launch range to fly their rocket, or unique external assets that are made available to support an on-orbit experiment. In the end the cadets must develop and maintain a willingness to proactively manage risk and quickly make decisions, coupled with extensive and accurate documentation of their processes. We foster a culture of risk being managed, not eliminated, with a test centric program appropriate of one of a kind, university-class spacecraft. We are time and budget constrained, it is compulsory that we remain agile, comprehend the issues and risks, and manage them effectively. The triad of trust that quickly develops is between the cadets, their faculty, and the technical staff in the lab. This trust and confidence in each other fosters and forces a "step up and be willing to make a decision" mind-set in the interest of the mission as well as demanding open communication so that we can press on armed with the decision.

ORS Challenges Illustrated

There are many examples of the capstone programs placing cadets in ORS-like scenarios where they are put to the test to solve a problem and press on swiftly to build and fly a space system. USAFA's doors are always open for people to look in on this unique "learn space by doing space," hands-on educational process where they can see this ORS proving ground. In the balance of this article, we will highlight some recent challenges in each of the three capstone experiences and illustrate these scenarios as applicable in preparing future ORS leaders. Our program goal is to prepare our cadets to serve as officers able to make informed, timely decisions to positively affect acquisition and operational decisions in the space community or whatever career-field they choose. Their skills will be honed with the experiences they gain as officers serving alongside others who may have experienced hands-on space via university-class satellites or similar rocket programs, rated operations, and current space and missile programs.

Figures 2 and 2a. FalconLAUNCH-6 explosion and FL-8 successful test.

FalconLAUNCH is an annual build and launch a rocket experience for the cadets. They faced a "failure is not an option" class challenge on 4 November 2009 when a rocket static fire test went awry and suffered a widely publicized system failure and explosion. Looking on was Mr. Gary Payton, deputy under secretary of the Air Force, who circled up with the cadets and wished them well in their "what happened" post-test analysis. He concluded "you'll learn more in conquering this failure than if you had succeeded." An April 2010 launch was no longer in sight as the cadet's design and ability to accomplish the mission came into question. Quickly, they organized an accident investigation and called upon faculty, industry experts, and Air Force veterans who have been here before, unraveling a booster failure or a space accident. They swiftly learned how to "what if" their entire design by developing fish-bone cause and effective diagrams and left no feature of their design free from scrutiny. They analyzed high-speed video evidence and used small scale experiments to verify design and functionality. In the end, in their zeal to reduce weight and push to get the Mach 3+ speeds the experimenter demanded for a test of a newly designed winglet, the cadets had altered the ignition system and found they had journeyed too close to the "knee in the curve," creating a far more explosive effect than the desired controlled ignition. They reported their findings within five weeks and even submitted a report to Mr. Payton for his review and comment. Armed with change, the cadets redesigned and experienced the thrill of technical victory as on 10 January 2010 their static fire went off without a hitch or explosion, gathering important performance data for the scheduled April 2010 launch.

As this article is in preparation, the FalconLAUNCH team faces a programmatic challenge in that the planned White Sands Missile Range (WSMR) launch site is no longer available for the April 2010 launch. With the design complete and manufacturing in full surge, the cadets are now assessing alternate launch ranges including a great offer from Fort Carson for the use of their Piñon Canyon maneuver site in southern Colorado. They face many issues associated with the change in launch venue, including the logistics, costs, and scheduling (within USAFA constraints) of a team launch deployment. In addition to having to prove their readiness and worthiness to safely fly on the new range without a thrust termination system, they must also reassess and explain to their customer the impact of the new launch site on their experiment. Most stressing is the need for Mach 3 speeds for at least three seconds of the ascent phase of flight. Immediately through analysis the cadets realized that the 4,000 foot altitude advantage offered by WSMR was negated in the sea level launch options. The need to control and possibly reduce launch vehicle weight became apparent as simulations showed that the first 4,000 feet of charging through dense air threatened the Mach 3 speed and duration requirements. Many issues remain in work here as this article goes to press, all under control of the cadets who are motivated to meet their customer's requirements and see their rocket fly before they toss their hats at graduation in late May 2010.

Figure 3. FalconSAT-5 and cadets during Edwards AFB, California test campaign.

On the FalconSAT front, this year involved preparation for the launch and operation of FalconSAT-5. The design of FalconSAT-5 began in the spring of 2007 and has progressed with the diligent work of the USAFA classes of 2007 through 2010. The mission includes experiments reviewed, approved, and ranked by the Space Experiments Review Board to measure the ambient and disturbed space environment, characterize space environment disturbances caused by on-board thrusters (cold gas ammonia, and a Hall Effect ion thruster), and characterize antenna and communications system performance in the same environment.

The 2009-2010 academic year began with final construction and integration of payloads into the flight model, followed by two major space vehicle test campaigns at the Air Force Research Laboratories Space Vehicles Directorate (AFRL/RV) at Kirtland AFB, New Mexico and then at Edwards AFB, California working with the AFRL Propulsion Directorate (AFRL/RZ).

In less than three months, 20 cadets and 10 staff members planned and executed two major deployments of personnel and equipment of two weeks each to move and recover FalconSAT-5 and its mobile ground station and equipment (ranging from spare parts to bunny suits for use in clean rooms). Not only is this pack-and-go chore relevant to ORS fast moving activities, it also prepares our cadets for rapid deployment in their Air Force careers. The two test campaigns had different focuses, but sought to boost confidence that FalconSAT-5 could survive the harsh launch environment, as well as the vacuum and extreme thermal environments of space over the planned three-year mission life. The AFRL/RV supported FalconSAT with the use of their large thermal-vacuum chamber, as well as other test fixtures and capabilities. The same cadet "employees" who built the satellite would now be pressed into responsibilities as testers and operators of their craft using the FalconSAT-5 mobile ground station (MGS). Acute attention was given to the use of the testing MGS since, in the end, it is the backup permanent system that could be used to fly FalconSAT-5. Five thermal-vacuum cycle episodes were completed over an eight-day timeframe where the cadets were monitoring the satellite 24/7. Sixteen test campaign scenarios were run. Most of the cadets in the FalconSAT-5 capstone class got their turn at "flying" the spacecraft in the chamber. Though these were carefully orchestrated test and monitor activities, the designers, builders, and testers received a good dose of insight into how their bird would behave on orbit. This first-hand experience formed the baseline for the Edwards AFB trip two months later.

At Edwards AFB, another unique and beneficial AFRL asset would be applied to proving FalconSAT-5's readiness for spaceflight. The Edwards chamber would enable the cadets to activate and fire FalconSAT-5's 800-Watt Hall Effect Thruster propulsion system and determine how the FalconSAT-5 spacecraft performs during this most demanding activity on-orbit. With the expert mentors guiding the way, much was learned about the spacecraft's ability to fire the thruster and balance the operations of essential spacecraft systems. Of greatest benefit was the clear comprehension of how FalconSAT-5's processor, timing system, and power system (solar arrays, batteries, and distribution and regulator systems) handled the high power draw of the propulsion system during firings. Once again, the builders were strapped-in as the flyers, and the steep learning curve climbed as the Edwards campaign came to a close. A lot of analysis awaiting the cadets, as well as the potential call to ship the spacecraft to the launch base.

Several system operations issues were discovered during the Kirtland AFB and Edwards AFB test campaigns and were resolved systematically once the satellite was returned to the USAFA Astronautics Laboratory under the guidance of faculty and staff. Anomalies were isolated through a series of tests and solutions identified. The entire process culminated in a successful Pre-Shipment Review presented by cadets to the Space Test Program senior leadership on 17 February 2010 after which the cadets received approval to ship the satellite to the launch site.

In early August 2009, when this academic year's FalconSAT class started, the FalconSAT-5 spacecraft was an assortment of parts, a mature and tested design, and a team of mentors ready to transform their 20+ cadets in the class from curious onlookers, to builders, testers, and operators. The cadets in the class comprised a wide array of engineering, science, and management majors. Throughout the semester it was impossible to tell who was majoring in what as they all rolled up their BDU sleeves and performed duties ranging from completing analyses to working in the clean room building their ship. In the fast and agile race to readiness, everyone stepped up to a variety of duties ranging from tightening and securing bolts and wiring harnesses to taking data while in an environmental test chamber to complete the vital verification and validation requirements to convince the program office we are ready for flight. The sense of ownership was truly reflective of the kind of attitude needed in ORS spaceflight preparation and operations.

With spacecraft shipment to Kodiak, Alaska around the corner, the cadets are focused on permanent ground station set up and checkout, mission planning, and crew force education and training. Again, the same cadets who were once suited up in the clean room or uncrating their spacecraft at the launch base are now the initial ops crews and responsible for the handoff to the future FalconSAT and FalconOPS capstone cadets in the classes of 2011 and beyond.

Figure 4. USAFA FalconOPS ground station.

FalconOPS is focused on the space operations paths many cadets choose to pursue. This academic year the focus has been on FalconSAT-3, the previous cadet satellite launched March 2007 aboard a Space Test Program-sponsored Atlas V launch vehicle and currently in its third year on orbit. FalconSAT-3 began its journey in an auspicious manner in a long and arduous early orbit checkout phase caused by some unexpected flight computer software issues identified only after orbit had been achieved.

The 8 March 2007 launch of FalconSAT-3 went off without a hitch. After a 12-hour wait, the first contact and attempt to turn on the spacecraft transmitter was met with silence—"USAFA, we have a problem!" A 25-day marathon of troubleshooting, testing, and perseverance ensued as the staff and cadets, and later the main spacecraft processor contractor, worked to determine the problem that was keeping their spacecraft from phoning home. The journey that culminated in the cadets getting their spacecraft back on track for commissioning and experiment operations showcased the skills and processes that can be called upon to rapidly work a showstopper-class problem and get a mission underway.

Figure 5. FalconSAT-3 liftoff.

Early in the effort there was tendency to fixate on what individuals believed the problem was and drill into the hypothesis. For example, during testing at Kirtland AFB, there was a "processor too cold" phenomenon identified where the processor would simply not start. The temperature bounds were noted during the tests and, believing this might be the case now that the satellite was on orbit, the staff and cadets proceeded at first along this line of investigation. They examined the orbit and lighting, however, and soon realized this scenario simply was not the case—it was a blind alley, but one possibility eliminated.

Fault analyses and processes were in work around the clock as the orbiting FalconSAT-3 remained in its unknown state. Three times a day, FalconSAT-3 flew within view of the USAFA mission control station and attempts were made to turn on the transmitter without results. The team decided to try an emergency path in using the "fire code" receiver to literally reboot the spacecraft processor. After 10 days, the team still had no luck.

The contractor was now involved and leveraged their commanding resources and insight into their processor's software to devise an approach that would get the spacecraft to report basic telemetry and status, but not try to run resident software that may be corrupted somehow. On the tenth day the attempt was made, a glimmer of hope emerged as FalconSAT-3 reported 64 data points and reported, "I'm AOK—power, thermal, and good system health—talk to me!" The tenacity and relentless attack was paying off. The cadets now had the tools to dump the non-volatile memory and compare that with the duplicate set of avionics on the ground. After detailed practice runs on the ground setup, a multi-pass campaign retrieved the memory image and confirmed that a major problem had occurred and the resident software was corrupted.

With the spacecraft limping along on the basic operating system (as in running a desktop computer in the basic input/output system setup screen), a plan was developed to reload the software via this tenuous pathway into the processor. The contractor developed a small "crutch" program that would enable cadets and staff to carefully upload a new operating system image and moving it to a different location in memory. A whole new game plan was drawn up and the cadets were educated as to what they would be doing, they trained on the control system and practiced uploads on the FalconSAT-3 qualification model that was operating in parallel within the Astro Lab. Armed with this confidence, they stepped in and executed a series of FalconSAT-3 supports to reload the correct software and, after 25 days, have their spacecraft in a state they'd originally desired 12-hours into the mission.

For 40 cadets it was a lesson that no classroom setting could bring to life. They saw it all—from chasing possible causes to literally rebuilding the spacecraft software load through a back door. They saw the synergism between engineering and operations, government and contractor, novices who invested years into their project, and seasoned experts who have earned their stripes. The tenacity and discipline paid off as they learned their spacecraft was functioning well (as designed) and simply in need of a do over with regard to functional operating software to get back on track. The first 25-days of FalconSAT-3 gave 40 cadets a chance to persevere and ultimately succeed in the world of anomaly investigation and resolution. They will not be rookies if they ever run that gauntlet again, perhaps with a time critical operationally responsive mission needed by the joint commander.

FalconSAT-3 areas of endeavor this academic year include resuming the on-orbit spaceflight testing of an innovative AFRL/RZ sponsored micro pulsed plasma propulsion system ideal for micro and smaller satellites. Eight functional thrusters had accrued less than one hour of firing time and then only in carefully orchestrated 10-minute command and monitor episodes in view of the FalconOPS ground station. The AFRL customer sought far greater test data and expressed their desire to achieve the 40-hour threshold goal on the thrusters, as well as an attempt to use these to alter the attitude of FalconSAT-3. With this somewhat urgent and timely need, the cadets and their mentors reviewed the experience base of on-orbit data and completed several back of the envelope analyses to prove to themselves they could push the envelope with the testing and not recklessly cross the line into system failure. A series of confidence tests were devised and executed with both line crews at the helm and the cadets who ran the calculations looking on ready to step in and help if needed. Single thruster full-orbit tests were followed by multi-thruster tests over a full orbit. Additionally, the cadets used an onboard plasma sensor to detect and verify the thruster was firing. With this steady, stair-step process expanding the envelope of capability and no adverse affects experienced, bolder tests were devised and executed including multi-orbit/multi-thruster test firings. In the end, the cadets assessed their spacecraft's ability to sustain long duration thruster firings and to support tests that are now capturing the on-orbit test data necessary to advance this AFRL innovative propulsion system.

ORS calls for agile and responsive analyses and decision making. Just before the 2009 holiday break, an opportunity arose in which, in less than four days, the cadets, teamed with scientists from the Los Alamos National Lab (LANL) to execute a close fly-by (less than four km) and leverage the Los Alamos team's willingness to use their Cibola satellite's sensors to assess an attitude determination and control glitch FalconSAT-3 was experiencing. Cibola journeyed to space alongside FalconSAT-3 on the same Atlas V booster nearly three years earlier. They separated from the upper stage and secondary payload adaptor at different scheduled times in the early mission and then, with each possessing slightly different drag characteristics, the two small spacecraft moved over time into different orbit planes. However, every 200-225 days they revisit each other in a close fly-by. With FalconSAT-3 experiencing a wobble and on-board sensors measuring and characterizing it, this seemed like an excellent opportunity to augment these data with off-board observations.

Following contact with Dr. Diane Roussel-Dupre, leader of the Cibola space mission, the idea became an operational mission and a joint LANL-USAFA quick reaction assessment commenced. The close approach was just four days away and precise orbit data was exchanged as well as information on each other's spacecraft characteristics. The cadet operations crews needed to quickly configure FalconSAT-3's sensors for the fly-by. Cadets Ben Shoptaugh and Bill Percoski not only faced their final exams week, they also faced high winds (very common to the Front Range of Colorado) that adversely affected antenna pointing to get the commands before the fly-by. Perseverance and tenacity was the order of the day as they kept commanding FalconSAT-3 and waiting for a break, which came just in time. The fly-by went without a glitch and the data was matched with technical support from STRATCOM's off-board capability that confirmed we were interpreting our FalconSAT-3 on-board instrumentation correctly and now able to confidently execute a campaign to fix the wobble and get back to the gravity gradient stabilized mode needed

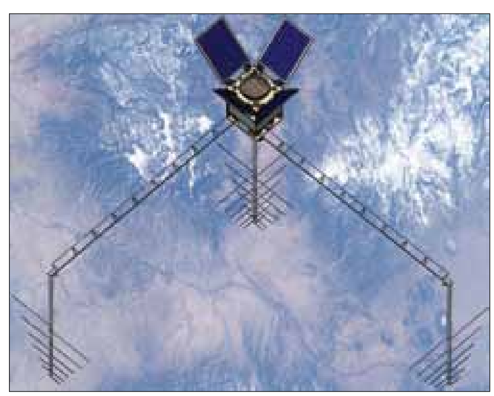


Figure 6. Cibola spacecraft.

for further experimentation supporting on-board experimental sensors.

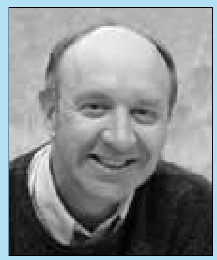
Graduates Experienced and Ready for the ORS Challenges

How do the USAFA space programs prepare ORS leaders? Our astronautics capstone programs place the cadets in an educational environment that gives them first hand and hands-on challenges, trials and tribulations of an agile, responsive, and fast moving satellite and rocket development, construction, and operations projects. We foster agile decision making, analytical processes to support the decisions, flexibility and risk tolerance, and a sense of trust and courage in each other such that our customers keep coming back to have their payloads and experiments journey to space and commence or complete their mission objectives.

Figure 7. 2d Lt Liz Bupane of the 5th Space Launch Squadron, a 2008 USAFA graduate and alumna of the FalconSAT program.

Recent graduates of the USAFA astronautics and space operations capstone courses serve in the space and missile operations (13S career field), on acquisition duty at the Space and Missile Systems Center (SMC) and other organizations, as developmental engineers duty at laboratory, system program office, and operational locations, and in rated assignments flying and fighting in support of contingency and combat operations around the globe. A large number have been picked for immediate graduate school education to the Massachusetts Institute of Technology (MIT), the Air Force Institute of Technology, Oxford University and the University of Surrey (United Kingdom), University of Colorado at Colorado Springs, and other world-class aerospace engineering programs—in most cases as a direct result of the experiences gained from the FalconSAT/LAUNCH/OPS experiences, and the world-wide notoriety of our programs. In fact, SMC sponsors two FalconSAT graduates per year with scholarships to MIT's systems engineering (SE) program to bolster Air Force SE expertise in the space acquisition community. Once their advanced studies are complete, our graduates take their places among the officer corps and across the spectrum of career fields, honed and ready to join the Department of Defense ORS team in many cases (now or later in their career) and apply the lessons learned in our unique capstone courses.

Col Martin E. B. France (BS, Engineering Sciences and Engineering Mechanics, US Air Force Academy [USAFA]; MS, Aeronautics and Astronautics, Stanford University; MS, National Security Strategy, National War College; PhD, Engineering Science and Mechanics, Virginia Tech) is professor, USAFA and head of the Department of Astronautics. He commands the Department of Astronautics with final responsibility for curriculum, personnel, research, budget, long-range planning, faculty development, and cadet instruction. Colonel France's professional experience includes research and development assignments with the Air Force Research Lab working on high energy laser systems, as the Air Force engineer and scientist exchange officer to France, assigned to Toulouse, France, as a program manager at the Defense Advanced Research Projects Agency, and as chief scientist of the Joint Improvised Explosive Device Defeat Organization.



Col John F. Anthony, USAF, retired (BS, Astronautical Engineering, US Air Force Academy [USAFA]; MS Astronautical Engineering, Air Force Institute of Technology) is a member of the US Air Force Academy's Department of Astronautics Space Systems Research Center staff. He is a 26-year Air Force veteran having served in many space operations and engineering roles in research, development and engineering, space systems acquisition, operations, astronautics and space systems education and training, and unit leadership. He served as a flight test engineer, logging more than 450 hours on aircraft test missions. He was an astronautics teacher at the USAFA 1982-86. Colonel Anthony commanded the 1st Space Operations Squadron 1996-98 and served in many space acquisition and operations leadership roles with US Space Command and the National Reconnaissance Office (NRO).

Prof. William W. Saylor (BS, US Military Academy [USMA]; MS, Nuclear Engineering, Massachusetts Institute of Technology [MIT]) is a visiting professor in the Department of Astronautics, USAFA. He is the Schriever Chair and is also the chief engineer for the Space Sciences Research Center. Following graduation from MIT, Professor Saylor was stationed in Ft. Belvoir, Virginia and ran the Nuclear Power Plant Operator's School before being assigned to Saudi Arabia as an assistant engineer. Upon leaving the Army, Professor Saylor worked as a nuclear engineer in the power industry before spending 12 years at Los Alamos National Laboratory working in a variety of advanced energy and defense programs. He developed energy plant conceptual designs based on heavy-ion accelerators and inertial fusion. Professor Saylor also supported numerous advanced system concepts for the Strategic Defense Initiative Organization Program Office and designed and built instrumentation and controls systems for various laser projects. He was also a project leader for several space engineering projects including payloads and small satellites. After an extensive consulting effort introducing new technologies into the power industry Professor Saylor has been a senior scientist at SAIC, Inc. supporting numerous Department of Defense and NRO space activities for the previous two years.

Gemini 76: Lessons From the Past and Visions for the Future

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A Vision for the Future (Part I)

The year is 2025. It is a typical early, humid summer day at Cape Canaveral, Florida. The thunderstorms that delayed the launch around noon yesterday have since passed—the next line of weather with electrical activity and unacceptable winds is not predicted to arrive at Canaveral until 1722 this afternoon, plus or minus a minute or two, thus giving about an hour to launch. In 15 minutes the pad-servicing robot will return to the launch vehicle for a final safety checkout in preparation for oxidizer loading of the hybrid first stage.

A great deal was riding on the success of this plan—a plan that was hatched only two months ago. Many had said it was an utterly ridiculous idea, including some of those who had since come onboard to lead a risky, fast paced strategy to orbit a new and vital capability needed in a nascent regional conflict that had global implications. National security was on the line, and so too were a few reputations. Only eleven days ago, a battlefield intelligence collection spacecraft had been placed into orbit from the same pad hosting today's launch. That launch had been completely expected to take place when it did, having been planned that way almost six months ago. What was not planned is that it was flown without an operable mission processing system. Just 50 days in the past, that mission processing system was found to have a severe set of systematic defects—defects that would take at least four months to fix. The events on the other side of the ocean that the spacecraft was intended to monitor would take no holiday. Luckily, the sensing spacecraft had been designed and built to have the capability to operate as part of a distributed networked system—a low power "Wi-Fi"-like crosslink from it to another specialized spacecraft about 10 kilometers (km) nearby could provide a relay direct to the ground via a high data-rate downlink, thereby completely bypassing the need for onboard processing. This capability was built-in for a demonstration test intended to take place much later in the year, with one of a cluster of other spacecraft yet to be placed into orbit. Today that specialized downlink spacecraft was on the pad, ready for launch and rendezvous with the sensing satellite now circling overhead. There were a mere 72 hours remaining to commence the battlefield tasking currently demanded by US Strategic Command. This whole idea of back to back launches and rapid rendezvous was dreamed up by a few entrepreneurial contractors on the same day the mission processing system problem was discovered: only two days later the plan had made its way all the way to the president for authorization. It had better work.

The future mission portrayed here has as its foundation operational responsiveness. Rapid turn-around launch, streamlined planning and operations, quick checkout, and timely augmentation are themes. Also noteworthy is what responsiveness brings: not only the capability to rapidly provide services during predictable contingencies, but also the ability to execute missions previously not even considered. Part of this story, too, is one in which both local and national decision makers are provided with options that can be exercised on short timelines in a time of crisis. Science fiction? Well, in a way, "yes." But, in another way, "no." You see, although a few of the technologies described above are not yet available, the execution timelines, mission profiles, national security implications, flexible planning, and options-based decision making did at one time exist, and in fact, were demonstrated just over 40 years ago. The foundation of this claim is a manned spaceflight mission, dubbed "Gemini 76." The mission featured two spacecraft, launched back to back from the same pad within eleven days. Together they carried out the first ever-orbital rendezvous. Without the exercise of this mission, the US' plan to execute President John F. Kennedy's call to land a man on the moon before 1970 would be in jeopardy, risking national technological advantage—both perceived and real. A short story of Gemini 76 now follows. Read closely, and realize that what one might think is fantasy, is not. This is not the stuff of science fiction: it is history.

Lessons from the Past

The JFK Imperative

… I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.…

~ President John F. Kennedy

On 25 May 1961, before a joint session of Congress, President Kennedy proposed placing a man on the moon before the decade of the 1960s had ended. Kennedy's straightforward vision was a direct challenge to the Soviet Union. Nearly four years had passed since the US had endured the launch of Sputnik and rushed to fill the technological void. Then, just three months into Kennedy's presidency, on 12 April 1961, Cosmonaut Yuri Gagarin was launched into Earth orbit. It was yet another Soviet shot across the bow of American scientific and technological prestige. Thus, landing a man on the moon was foremost politically motivated to reverse the perception and po-

Figure 1. President John F. Kennedy before Congress, 25 May 1961.

tential reality of Soviet technological dominance: a lunar landing was indeed a national security objective. In proposing a trip to the moon, Kennedy was thinking in the context of victory. In a memo months before to Vice President Lyndon B. Johnson asking if a lunar mission were possible, the president spoke in terms of "beating" the Soviets and a desire to "win."[1] Kennedy's challenge was not without risk: Only three weeks before his speech Alan Shepard had been launched on the first Mercury spacecraft. It had been a 15-minute suborbital ride that had ended a mere 300 miles downrange of Cape Canaveral. In May 1961, several key capabilities needed for a lunar mission had not been developed and tested. Chief among them were the ability to, first, provide for and sustain long duration spaceflight (much longer than 15 minutes, in fact approaching periods on order of a week) and second, design of a space system with sufficient energy and efficiency to propel a man-carrying vehicle to the moon and back. It would be the latter requirement that would be the most challenging, and in the end would create the need to execute the spaceflight technique of rendezvous.

The Case for Rendezvous

…Because of the lag in launch vehicle development, it would appear that the only way that will be available to us in the next few years is the rendezvous way…[2]

~ National Aeronautics and Space Administration (NASA) Engineer John Houboult, May 1961

Development of a launch vehicle capable of lifting a manned system that could land on the moon and return was a serious engineering challenge. Initially, a giant rocket called Nova was designed by Werner Von Braun to carry out this task. In a mission sequence known as "direct ascent," a Nova booster would provide sufficient energy to a single capsule capable of getting to the moon and back again.[3] Another concept, also proposed by Von Braun, was deemed "Earth orbit rendezvous." It would launch elements of a lunar landing system into Earth orbit. These elements would be assembled and then sent on their way to the Moon, potentially some orbital refueling would be involved.[4] Many considered direct ascent as the most obvious and lowest risk approach to a moon landing. Then, in studies later promoted by John Hoboult at the NASA Langley Research center, a third technique gained attention. Described as "lunar orbit rendezvous" (LOR), this distributed approach proposed launching together a tandem of spacecraft into lunar orbit, one of which would land on the Moon. That spacecraft would then leave the moon, and then rendezvous and dock with the second spaceship, which would be designed for a fiery return to Earth.[5] There was a great deal of debate within NASA on the risks and benefits of the direct ascent and the LOR method. Nova was a big rocket—but at the time building a bigger rocket appeared to some to be less of a risk than to rely on a method involving rendezvous, which in the early 1960s was but an academic exercise carried out by astrodynamicists. Advocates of LOR were in the minority, but Houbolt boldly went to NASA headquarters with his idea. Eventually key leadership recognized that indeed, a Nova development program would risk busting Kennedy's timeline, and LOR won out with NASA management in the summer of 1962 (even though Kennedy's science advisor disagreed).[6] With this decision the smaller moon rocket, the Saturn V, could be used. In making this choice, it became critical to practice the art and science of rendezvous in orbit very soon, in order to prove its viability. It would be up to a new manned program, Project Gemini, to demonstrate that it could be done.

Project Gemini: The Spacecraft

All in all, Project Gemini served as a bridge between the rudimentary Mercury capsule and the sophisticated Apollo spacecraft, a bridge between President Kennedy's bold statement and the national capability to execute it…[7]

~ Maj Gen Michael Collins, Gemini X and Apollo 11 astronaut

At first conceived as a "new and improved" Mercury (in fact originally called Mercury Mark II),[8] the two-man Gemini spacecraft rapidly became a vital transition to Apollo, the three-astronaut system that would take men to the moon. Gemini would first test that both man and machine could survive long-duration missions. The capability of the machine to sustain long duration space-flight challenged power subsystems.[9] Power on Mercury was provided by batteries—the longer flights on Gemini would necessitate the implementation of new fuel cell technology to save weight. Gemini—built by prime contractor McDonnell (also the prime on Mercury)—would be required especially to prove that the technology and techniques of rendezvous and were viable in orbit, thus paving the way for LOR on Apollo. Rendezvous capability on the Gemini capsule was provided using vast improvements in propulsion and attitude determination and control. Included in this array of new technology were a simple computer (with 160Kbits of RAM) and a C-Band rendezvous radar. The Gemini spacecraft was also unique in that it utilized an ejection seat system in place of a rocket abort tower—this was a design decision based on an attempt to limit complexity of the capsule design. Although not specifically called out in any NASA requirements, James Chamberlain, the initial program manager for Gemini, insisted on a simplified system design.[10] Indeed, modularity, testability, and serviceability were fundamental design principles of the Gemini spaceship.

Project Gemini: The Launch Vehicles and Targets

The US Air Force has played a very key role throughout the first space age.... Space launch vehicles that formed the basis of the later Mercury flights and all the Gemini flights came off of the drawing board of General Bennie [Bernard A.] Schriever's team in the Western Development Division—today's Space and Missile Systems Center in Los Angeles, California.[11]

~ General C. Robert Kehler, commander, AFSPC

The Air Force began its Titan II Intercontinental Ballistic Missile (ICBM) program in June 1960, with Martin in Baltimore as the prime. Eighteen months later, in January 1962, the rocket was chosen to lift the approximately 8,000 pound Gemini spacecraft into orbit.[12] Thus began a joint development program—one for a ballistic missile, the other for a man-rated vehicle. Overall responsibility for the development of the Titan II for Gemini remained in NASA's hands, but the agency placed the Air Force's Space System Division in Los Angeles in charge to manage the rocket system's contractors.[13] Titan II's strengths were simplicity, reliability, and ease of integration. Titan was also a "quick-turn" launch vehicle since it used storable hypergolic propellants; with a blend of hydrazine fuel and nitrogen tetroxide oxidizer. This hypergolic combination ignited and burned spontaneously on contact and required no ignition system. The propellants could be stored and used at normal temperatures in contrast to the cryogenic propellants used by the Atlas booster used for Mercury or the Titan I ICBM.

Prior to the launch of the first Gemini, Titan II had been through 32 test flights, of which 10 were plagued with problems—famous among them longitudinal oscillations referred to as "pogo." The phenomenon had little impact on the ballistic missile's performance, but anything above 0.25 g's was unacceptable to NASA.[14] Titan ultimately came through with 12 nearly flawless test flights that showed the Air Force had indeed solved the problems and had provided a manned-rated launch vehicle. Placed into ICBM service in 1963, Gemini's Titan was ready early spring 1964 in time or the first Gemini test flight.

With rendezvous and docking top among the list of Gemini objectives, an orbital target had to be provided: an Agena D upper stage was adapted for such tests. Although not known publicly at the time, Agena had served since 1959 as the upper stage host for the Corona film-based reconnaissance satellite program. An Atlas first stage would be used to boost the Agena. Lockheed in Sunnyvale, California, built both vehicles.

Project Gemini Lifts Off: The Clock has Started

…They were going to catch that …[Titan stage] target vehicle, and these astronauts were used to those Corvettes, and when you want to pass somebody you push the foot to the floor and zoom around them. Well, they line up behind this target, they're going to catch it, and they shove the throttle forward, and the more they burned their rockets, the further behind they got and the further behind they got, and they couldn't understand why for a while."[15]

~ Henry Pohl, NASA, chief, Propulsion and Power Division, Project Gemini

Gemini I lifted off from Launch Complex (LC) 19 of the Cape Canaveral AFS on 8 April 1964. LC 19 would host all 12 Gemini launches: it would remain the only pad capable of supporting Titan flights for the program. The first Gemini flight was an unmanned mission that focused on testing of the spacecraft and launch vehicle. Unmanned Gemini II followed in January of 1965. The first manned Gemini mission, Gemini III, launched in March 1965 for a three-orbit test flight with Gus Grissom and John Young onboard.

Gemini IV followed in June. In this, the first multi-day (four days) manned mission for the US, a stationkeeping exercise was added: Astronauts James A. McDivitt and Edward "Ed" H. White would attempt to close and hold station with the final stage of the Titan II which had followed them to orbit. Gemini IV did not carry a radar, meaning computer aided rendezvous calculations could not be made. So, this was a "by the eyeball" approach that was an utter failure, proving the non-intuitive nature of orbital mechanics. McDivitt attempted to fly like an aircraft pilot would toward the target, thrusting directly at it. The laws of Kepler won this battle. The aim and thrust technique made matters worse as the upper stage pulled further away.[16] The orbital mechanics lesson demonstrated was the basic principle that in order to catch up, one really has thrust in the opposite direction. In failure came success, as the flight and operations crew learned a great deal. Also of significance was that astronaut Ed White did conduct the first ever spacewalk in the history of the US space program.

Gemini V then lifted off in August 1965. Carrying the Gemini radar for the first time, the crew ejected an evaluation pod which was intended to act as a basic rendezvous target. Problems with a fuel cell resulted in cancellation of the rendezvous exercise on Gemini V—a successful practice run was conducted instead on an imaginary target. With the safe splashdown of the third manned Gemini mission, the true test of rendezvous would come using the Agena target starting at long range. The next Gemini mission, Gemini VI, would be assigned this task.

Gemini VI: From Failure to Innovation

You're out of your minds. It can't be done.[17]

~ Director of Flight Operations Christopher Kraft, October 1965

On the morning of 25 October 1965, the pace of activity was frenetic at Cape Canaveral. At Launch Complex 14 the Agena that would serve as the target for the first ever orbital rendezvous was being readied for flight on its Atlas booster. Just a mile to the north, at LC 19, stood Gemini VI atop its Titan II rocket. At 0945, just hours after a breakfast of steak and eggs, Astronauts Thomas P. Stafford and Walter "Wally" Schirra climbed into their Gemini capsule, preparing to track down and fly in close formation with the Agena. Just minutes later, at 1000, the Atlas/Agena climbed into the blue Florida sky. In the span of six short years, the Agena had flown an amazing 140 times on national security related flights.[18] Although this was its first manned spaceflight support mission, watching it soar skyward had become as commonplace as watching a train leave the station. Minutes later, as the vehicle became a dot to the naked eye, the Agena was released, and the Atlas fell towards the ocean. At this point the Agena would take over and place itself into orbit. The flight controller reported the separation, and then began to relay anomalous activity. The Agena appeared to be wobbling. The main engine did fire as expected, but NASA and Air Force officials from the blockhouse in Florida to Mission Control in Texas became nervous. Then, the range reported sure signs of failure: radars at Patrick AFB and MILA were tracking the Agena: all five pieces of it.[19] Fifty minutes into flight, Carnarvon tracking station in Australia should have picked up the Agena coming around the other side of the Earth. There was nothing there. "No joy—No joy" was reported by the NASA public affairs officer.[20] Back at the Cape, Stafford and Schirra exited their Gemini capsule. There was no target. There would be no rendezvous, and therefore no launch from the Titan pad at LC 19.

Looking on at the Cape were two entrepreneurial contractors, Walter Burke and John Yardley. Burke was the McDonnell vice president and General Manager for Spacecraft and Missiles. Yardley was his number two. Faced with unknown months of potential delay, Burke asked Yardley "Why couldn't we launch another Gemini as a target instead of an Agena?" He recalled a previous study of a rapid-fire launch demonstration by Martin, the Titan II contractor. Listening in on the chat were Frank Borman and James Lovell, the Gemini VII crew next in line for a 14-day long duration mission on Gemini VII scheduled for launch in less than two months. Burke further detailed his idea, going so far as to sketch out a concept where Gemini VII could be fitted with an inflatable cone as a docking mechanism. Borman drew the line on spacecraft modifications and pushed back. But, Burke and Yardley continued to brainstorm the overall concept. The two McDonnell engineers then tracked down George Mueller (NASA's manned spaceflight chief in Washington, DC) and Charles Mathews (NASA's Gemini program manager) and explained their radical thought. The two NASA officials were pessimistic.[21]

There was some hope: as it turns out, a rapid demo had been discussed a few months before and detailed by Col John Albert, chief, Gemini Launch Vehicle Division, 6555th Aerospace Test Wing, working with the Martin chief at Kennedy Space Center, Joseph Verlander; but, no one seemed thrilled at pursuing it, though some spare parts critical for such a move had been ordered and were in place. Now, two months later, the demo plan was dusted off. It had features that might help make Burke and Yardley's idea work. Still stinging from the day's failure, but not giving up on their new idea, Burke and Yardley described the details of the rapid launch demo to NASA's leadership and said that if two Titan's could be launched from LC 19 in under a two weeks span (the length of the Gemini VII mission), a back to back mission was definitely doable.[22]

Meanwhile, NASA was dealing with the yet to be understood Agena problem and trying to sort out what to do. Knowing that determining and correcting the Agena problem could take many months; several in the agency's leadership immediately began to focus on the upcoming Gemini VII flight. They were thinking to de-stack Gemini VI and try again in the spring of the next year, sticking to fly Gemini VII's long duration mission in early December as previously planned. The idea of placing the Gemini VII spacecraft on Gemini VI's Titan II was the favored option—swapping spacecraft would be much easier than swapping Titans.

Burke and Yardley left Florida for Texas. Once in Houston, Texas, the day after the Agena failure, they began to discuss their plan with Robert Gilruth, the director of the Manned Spacecraft Center (MSC). Gilruth listened politely, but said to Burke, "Walter, you know things aren't like that in real life." Burke, pressed Gilruth—yes it might be challenging, but what from an engineering point of view was preventing it from being done? At this point, Gilruth brought in backup. He asked his deputy George Low what he thought about the concept—Low replied that he was very intrigued by the idea, but did point out one potential issue: the Gemini tracking system was not designed to handle more than one Gemini spacecraft at a time. Still optimistic, Low asked Flight Operations Director Chris Kraft what he thought of the plan. Kraft first replied, "You're out of your minds. It can't be done."[23] Of course, "Has he lost his mind?" had been one of the first thoughts that came to Kraft when he heard Kennedy's speech to Congress in May of 1961.[24] Now, like then, Kraft gave it more thought and gave the idea a chance. Astronauts when asked about the plan of course loved it. Suddenly, what seemed to some as a totally ridiculous idea began to make a lot of sense. The context was once again vital to the technical discussion: NASA was on a mission to beat the Soviets to the Moon. Rendezvous was the bridge to that objective. On the other side of the ocean, the Russians appeared to be taking no holiday in their quest for technological dominance. The end of the decade was nearly a mere four years away.[25]

Word soon came from the Cape that the Titan II attached to Gemini VI did not have the capability to launch the heavier Gemini VII spacecraft (Gemini VI carried batteries for its two day mission, while seven would use fuel cells for its two week orbital stay). It was at this point that NASA had to even more seriously consider the Burke-Yardley notion. The Cape team now looked into a fast paced strategy involving a nine-day pad turn around. The initial assessment was that it could be done, although the tracking and control operations of two Gemini's in orbit were still a question mark. Kraft gathered his team in mission control and introduced the Burke-Yardley plan. Motivated, focused, and relying on their detailed systems insight, one engineer quickly figured out how to solve the tracking problem: the Mercury tracking system was still in place and could be used to handle Gemini VII while Gemini VI was in orbit. Rapidly things were falling in place, and even Kraft, who at first considered this a totally outrageous idea, was becoming convinced the plan could work.

A little more than 48 hours had expired since the "no joy—no joy" report of the Agena launch had been heard on the speakers broadcasting into the Florida air. Already, the press was beginning to ask questions about a dual Gemini mission. At this point, the leadership in Houston wasted no time in getting word of the idea to headquarters in DC. On the afternoon of October 27, the top NASA officials convened in Washington to formally consider the Burke-Yardley proposal. NASA Administrator James Webb listened intently as the point-counter-point discussion evolved. Webb was intrigued—but he needed to know the bottom line: would it work? Webb phoned George Mueller, his administrator for spaceflight, and asked the question. Mueller then passed that question to Gilruth in Houston. To add a bit of pressure, Mueller also informed the MSC director that if the plan was viable, Webb wished to immediately pass it along to President Johnson. Gilruth responded that he thought it was still a good plan, but wanted 30 minutes to convene his experts, including Kraft and Deke Slayton, chief astronaut, to take a vote. Mueller gave Gilruth 15 minutes. The concept had been discussed in Houston a mere 24 hours. Gilruth went around the room. The vote was unanimous: GO!

On Thursday, 28 October 1965, only three days since range radar witnessed the Agena explode, a press conference was convened to the west of Austin, just off Texas Highway 290, at the Lyndon B. Johnson Ranch. Press Secretary Bill Moyers announced to the national news media the details of an ambitious plan: NASA would launch two Gemini spacecraft into orbit on back to back missions and carry out the first ever orbital rendezvous. The combination mission would become known as "Gemini 76."[26]

Gemini 76 Takes the Stage

The day after the [President's] press conference, Flight Control was in high gear.… It was like watching Patton's Third Army break off their offensive, perform a pivotal maneuver, turn, and march 100 miles in the dead of winter to relieve Bastogne.[27] ~ Gene Kranz, Gemini flight director

On 29 October, the Titan II that would be used to launch Gemini VII was brought to LC 19 to replace its slighter weaker brother. At Goddard in Maryland, work was commencing on the reconfiguration of the tracking network that would allow two simultaneous missions. In Houston, crew training for Gemini VII's extended flight, and Gemini VI's rendezvous attempt, was in full swing.

On 4 December 1965 at 1430, Gemini VII's launch went off flawlessly and she began her 14-day marathon.[28] The mission profile was not that much different than had been originally planned many months ago. Only the orbit had been circularized in preparation for the Gemini VI rendezvous attempt. No sooner had Lovell and Borman gotten over the Atlantic had repairman and welders raced to the pad to begin cleanup and take care of any damage that had taken place. The damage

Figure 2. Aborted launch attempt of Gemini VI, 12 December 1965.

was in fact minimal. Instrumentation was replaced. In one day Gemini VI's booster was erected, the spacecraft mated, and all testing and documentation completed. The quick turn surged ahead—the launch team was ready for Gemini VI's launch on 12 December.

Sunday morning at 0954 the main engines of Gemini VI roared to life. The roar turned into a sputter and the malfunction detection system began shutting down the engines. 1.2 seconds after engine start, an electrical tail plug erroneously fell from the bottom of the booster. The purpose of this plug was to initiate the mission timer in the spacecraft to notify the crew they had left the pad. Thus, inside the spacecraft, there were indications that the rocket had begun its upward climb (the "clock" was running)—and that the main engines had shut down. Flight rules were clear: pull the D-ring, and await a 20g ride on the ejection seats. But astronaut Schirra relied on a very sophisticated decision-making tool known as "the seat of his pants" to realize the rocket was going nowhere. He remained unnerved by the lack of acceleration.[29] The pad crew quickly safed the system and the astronauts, for the second time, exited their capsule.

There were now only six days left in Gemini VII's flight. A typical turnaround after such a hangfire would take four days. That of course assumed the problem that caused the shutdown in the first place had been determined and fixed. By nighttime the engine maker, Aerojet, had discovered that the engine had shut down before the tail plug had come loose from its connector. Obviously the tail plug had been shaken loose by the

Figure 3. Photo of the Gemini 7 spacecraft taken from Gemini 6 during the first ever orbital rendezvous.

Figure 4. Gemini VI crew of Tom Stafford (left) and Wally Schirra (right) suit up in preparation for mission training.

vibration of the engine start, but the fact that it had fallen out was not a cause of the preemptive shutdown. Aerojet began a frantic search at the pad for the root cause of the failure. By morning the next day people were tired and knew little more than the night before. Then came the moment of discovery: backtracking through the engine's history it was determined that a small, thimble-size cover had been placed on the gas generator port prior to removing the generator for cleaning at the Martin factory in Baltimore. The cover had never been removed! Quickly personnel verified that, indeed, there was a cover at the oxidizer inlet port. The cover was removed, the generator cleaned and checked out, and the engine reassembled that same Monday.[30]

On 15 December, it was a typical relatively warm and humid late fall day at the Cape. A great deal was riding on the success of this plan—a plan that was hatched only two months ago. Many had said it was an utterly ridiculous idea, including some of those who had since come on board to lead a risky, fast paced strategy to orbit Gemini VI and test the technique of rendezvous for the first time. National security was on the line, and so too were a few reputations. Schirra and Stafford climbed into Gemini VI for their third launch attempt. At 0837 the engines of the Titan II roared to life. Five seconds later, the engines were still operating, and Schirra reported from the cockpit "Oh, the clock has started. It's a real one!" Gemini VI was on its way. Just less than eleven days after it's sister ship had left the same pad, Schirra and Stafford were on their way to execute tasking promised to the nation. At Titan II upper stage cut off, Stafford checked his on board computer and saw 7,830 feet per second; they were in orbit and the Gemini VI was on her way to join Gemini VII.[31] The rendezvous profile Gemini VI would fly was dubbed "M=4" and would involve four orbits or six hours of maneuvering to reach Gemini VII. Just past the half way mark, Gemini VI's radar lock signal flickered on as it locked onto Gemini VII. At five hours, five minutes into the chase, a bright star appeared in the cockpit window. Stafford made the report over to his commander Schirra, "Hey I think I got it. That's 7 Wally!"[32] Although Schirra first thought it was a star, it was indeed Borman and Lovell's spaceship. The tempo of mid course corrections picked up and an orbital dance commenced. Following braking and tweaking, and appropriately bringing down the range rate as the range closed, Schirra and Stafford brought their spacecraft to within 40 meters and zeroed out the relative motion between the two craft. For three orbits, Gemini VI worked with the passive Gemini VII "target." The two spacecraft stayed within 90 meters of each other and got as close as 30 centimeters—close enough to communicate using hand written signs.[33] Schirra and Stafford each took turns at the controls. Docking type approaches were flown and confidence soared as the four astronauts went through their paces. At one point Gemini VI "parked" 12 meters from Gemini VII and for 20 minutes stayed put in a stable and hands off manner. A 90 meter circumnavigation maneuver to fly around Gemini VII was accomplished. Believing the 90 meter goal not being representative of real station keeping, Schirra and Stafford repeated the fly around at 30 meter range.

As Gemini VII was about to begin its 12th day on orbit, Gemini VI bid the crew of Gemini VII a farewell with "really a good job Frank and Jim. We'll see you on the beach," and proceeded on with retro fire to come home to Earth.[34] Gemini VII would end her marathon mission successfully three days later.

The joint Gemini 76 mission captured the attention of the nation, with the entire rendezvous sequence appearing on the cover of the 24 December 1965 edition of *Time* magazine. The article inside related the vital significance of NASA's accomplishments in the days preceding:

> With their successful mission, the four astronauts leaped over past delays and put the US space program back on schedule. Pure science and practical engineering had cooperated to solve the incredibly complex equations of orbital mathematics. Human skill and human courage had added the vital ingredients that made the computations correct. Now the dream of docking two spacecraft while they whirl through their curving courses promised to be no more of a problem than parking a compact car.…
>
> NASA's timetable calls for the first US astronauts to explore the moon within four years, a goal that has always seemed unduly optimistic—by almost any standards. But Gemini's "Spirit of 76" mission last week dispelled most doubts. It brought the elusive moon into reach, and gave US astronauts good reason to start planning still more ambitious voyages, as hostile space began to show the first small signs of hospitality.[35]

Gemini 76 – A Look from the Present

Success in our work was never a given, for the margins were slim and the odds long. When our technology failed, as it often did, we banded together and we made it up in guts, hard work, and the determination to succeed."[36]

~ Ed Fendell, NASA, Gemini Missions Operations

The Gemini 76 mission is symbolic of an almost magical period in spaceflight, when decisions were made in rapid fashion by "steely-eyed missile-men" wearing headsets in Mission Control and white suits in space capsules.[37] What was it that allowed the rapid decision making and light-speed execution witnessed in the era? First, we believe all of the decisions of the period, especially those that have been recounted here, were firmly grounded in the context of well-focused objective. As former NASA administrator Mike Griffin recently pointed out to us, Kennedy's speech before Congress was the quintessential directive for achieving a goal. "Man, Moon, Decade":[38] The vision contained all that was needed to provide a desired end state within a specified time. In the case of rendezvous, it was a noble accomplishment to target, but it was most important because it was a means to a more ambitious (and clearly defined) end.

Certainly the machines of Gemini 76 enabled the rapid turn in the final months of 1965. The Titan II was an ICBM by design, and responded as an ICBM in action. James Chamberlain's vision of Gemini as a modular, simple, easily tested spacecraft paid dividends. But when we talked to some of the main actors involved about the success of Gemini 76, they focused on people and process. Gene Kranz, a Gemini flight director (who would later take over for Chris Kraft) keyed on the personnel in "… ops and admin being the same, just changing hats."[39] In other words, those responsible for flight operations were also the managers. As operators, they understood from a technical and operational basis the risk and opportunities of their decisions. As managers, they were enabled to make decisions with little bureaucracy. The man in charge of all flight directors, Chris Kraft, answered the go/no-go decision for Gemini 76 for the operations crew: he was only three men removed in the management chain from the president of the US.

We asked Capt Jim Lovell of Gemini VII and Lt Gen Tom Stafford of Gemini VI about the secrets to success of the mission recently. Lovell stated, "I don't think technology had much to do with this—it was the management…."[40] Stafford responded, "We didn't need a cast of thousands, or countless reviews, or rooms full of people, we had the goal and a can-do attitude accompanied with the will to succeed."[41]

As we look to the future, we may imagine many great technical solutions to provide responsiveness. But, the ability to truly be flexible and timely will ultimately depend on having the right people and a precise, yet limited, process. Even with that mix in hand, many may think that it is "unduly optimistic—by almost any standards" to be able to plan and execute national security space missions on time scales of months and not years; but, that same pessimism in people and machines has been proven very invalid in the past, especially when the objective has been made completely clear and a small group of people are given the authority to get the job done.

A Vision for the Future (Part II)

With twelve hours to spare, the downlink module took up station at 10 km from its sister spacecraft and an orbital dance commenced. It was a computer activated sequence that had begun five hours earlier, overseen by a lone space operations officer and her payload operator, who was seated next to her in the distributed space operations complex (in reality, the two were separated by about 1,000 miles). Automated cluster flight operations were confirmed. 10 minutes later the wireless link between the two modules was activated and data began flowing to the ground. It would be a busy night for the on-duty intelligence analysts.

The authors would like to thank the following individuals for participating in interview sessions and email exchanges during the writing of this article: Mr. Ed Fendell, Dr. Michael Griffin, Mr. Eugene Kranz, Capt James Lovell, LT General Tom Stafford, and Mr. Guenter Wendt.

Notes:

[1] John F. Kennedy, memorandum for vice president, 20 April 1961, presidential files, John F. Kennedy Presidential Library, Boston, MA.

[2] Barton Hacker and James Grimwood, "On the Shoulders of Titans: A History of Project Gemini," NASA Special Publication-4203, NASA History Series, 1977.

[3] The capsule would need to carry enough fuel to land on the moon and then launch and return to Earth. Thus, the capsule would be very large, and therefore the rocket needed to carry it huge.

[4] Although smaller rockets could be used, as many as 15 Saturn launches might be required to meet the landing requirements for a single mission.

[5] It was a very effective and efficient technique that, post-mission, left a large amount of space system mass not required for the return mission behind. The approach significantly reduced the size of the rocket required to launch the system out of earth's gravity well.

[6] Courtney G. Brooks, James M. Grimwood, and Loyd S. Swenson, Jr., "Chariots for Apollo: A History of Manned Lunar Spacecraft," The NASA History Series, NASA SP-4205, NASA Scientific and Technical Information Office, Washington, DC, 1979.

[7] Michael Collins, *Liftoff: The Story of America's Adventure in Space* (Grove Press, 1988).

[8] The single-astronaut Mercury capsule was a very rudimentary machine. Transported to the launch pad on the back of a truck using a mattress as a cushion during its initial testing phase, Mercury had only the capability to orbit the Earth for at maximum one day. Limited propulsion meant it could by no means attempt to rendezvous or even stationkeep with another object. Therefore, the ability to test long duration flight and rendezvous would be a capability to be assigned to another manned spacecraft system–that system would be Gemini.

[9] Environmental control subsystems were also challenged. In Mercury, bottled gaseous oxygen was sufficient for single day missions. Gemini would test missions lasting up to two weeks in length. Volume restrictions would force the two-man craft to be designed to use a liquid oxygen based system. See David Shayler, *Gemini: Steps to the* Moon (Springer-Praxis Books, 2001).

[10] For instance, Mercury's sequencing system was a largely automatic, but allowed pilot intervention, resulting in complex electrical circuitry. Gemini would rely on pilot control instead of just allowing it. Mercury's 220 relays and other switching gadgets were reduced to only 60 in the Gemini spacecraft. See Barton Hacker and James Grimwood, "On the Shoulders of Titans: A History of Project Gemini," NASA Special Publication-4203, NASA History Series, 1977.

[11] Gen C. Robert Kehler, remarks at the National Space Symposium, The Broadmoor Hotel, Colorado Springs, Colorado, 31 March 2009.

[12] "Escape Route Blocked in Silo Disaster," Associated Press, Ellensburg Daily Record, 13 August 1965, 1. The Titan II ICBM was in service in the USAF from 1963 to 1987. Although it had a distinguished service history, it was plagued with fatal incidents, including one which resulted in the deaths of 53 people in Arkansas.

[13] Barton Hacker and James Grimwood, "On the Shoulders of Titans: A History of Project Gemini," NASA Special Publication-4203, NASA His-

tory Series, 1977.

[14] Ibid.

[15] Henry O. Pohl, Johnson Spaceflight Center, Houston, Texas, 9 February 1999, oral history transcript, 29, http://www.jsc.nasa.gov/history/oral_histories/PohlHO/HOP_2-9-99.pdf. Pohl had an illustrious technical career with NASA, starting as a test engineer for Werner Von Braun and concluding as chief engineer for the International Space Station.

[16] Ibid.

[17] David M. Harland, *How NASA Learned To Fly In Space* (Burlington, Ontario, Canada: Apogee Books Publication, 2004).

[18] Barton Hacker and James Grimwood, "On the Shoulders of Titans: A History of Project Gemini," NASA Special Publication-4203, NASA History Series, 1977.

[19] Ibid.

[20] "Gemini VI Mission Scrubbed When Agena Fails to Orbit," Space News Roundup, Manned Spacecraft Center, Houston, Texas, 29 October 1965.

[21] Ibid

[22] Ibid

[23] Ibid

[24] Ibid

[25] Chris Kraft, *Flight, My Life in Mission Control* (Dutton, 2001).

[26] This of course was the strategic view. Down in the trenches, at the tactical level, the engineers and technicians were concerned about one thing: staying on schedule. See Ed Fendell, NASA Johnson Space Center, oral history transcript, 19 October 2000, 26, http://www.jsc.nasa.gov/history/oral_histories/FendellEI/FendellEI_10-19-00.pdf

[27] In the combination of mission identifiers, Roman numerals gave way to the Hindu-Arabic numbering scheme.

[28] Gene Kranz, *Failure is not an Option: Mission Control from Mercury to Apollo 13 and Beyond* (Simon and Shuster, 2000). As the title suggests, Kranz began his career at the beginning of manned spaceflight, and concluded with the Space Shuttle Program. He of course is most famous for his leading role in the successful recovery of Apollo 13.

[29] Crammed inside a small capsule with little room for privacy, Astronaut Jim Lovell later described the mission as "two weeks in the men's room" It was more than hyperbole: a leaking urine collection bag had created globules of liquid waste that floated about the cabin for the duration of the flight. (http://www.astronautix.com/flights/gemini7.htm).

[30] In our discussions with astronaut Jim Lovell (pilot of Gemini VII), he recounted that "no one would have survived" the ejection. Obviously this belief, documented by other sources to be held widely by the Gemini astronaut corps, was a major part of Schirra's risk calculus. Reference telephone interview conducted between the authors and Captain James Lovell, 17 February 2010.

[31] Barton Hacker and James Grimwood, "On the Shoulders of Titans: A History of Project Gemini," NASA Special Publication-4203, NASA History Series, 1977.

[32] Gemini VI, voice communications, air to ground, ground to air voice transcriptions, http://www.jsc.nasa.gov/history/mission_trans/GT06_TEC.PDF.

[33] Ibid.

[34] Borman, a West Point graduate was out numbered by the other three Gemini 76 crew mates who were all graduates of the Naval Academy, including Stafford who was an Air Force officer. During the close operations the Gemini VI crew taunted Borman with a makeshift "Beat Army" cardboard sign.

[35] Gemini VI, voice communications.

[36] "Space: The Moon in Their Grasp," *Time Magazine*, December 24, 1965. Reprints of cover are available at http://www.time.com/time/covers/0,16641,19651224,00.html.

[37] Ed Fendell, graduation commencement speech, Becker College, Worcester, MA, 9 May 2009.

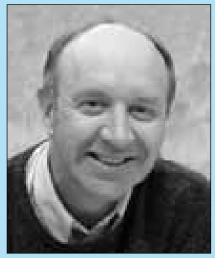
[38] Apollo 8, for example, was yet a similar story: many of the same people in charge of Gemini made the audacious decision to fly around the moon on only the second manned Apollo flight. This decision was made once it was realized the first Lunar Module would not be ready in time for Apollo 8's originally intended mission—a Lunar Module test to be conducted in Earth orbit.

[39] Personal conversation with Dr. Michael Griffin, 23 February 2010, Washington, DC.

[40] Mr. Eugene Kranz, telephone interview with authors, 15 September, 2009.

[41] Capt James Lovell, telephone interview with authors, 17 February 2010. Lovell later flew on Gemini XII, Apollo 8, and served as the commander of Apollo 13.

[42] General Tom Stafford, telephone interview with authors, 29 August 2009. Stafford later commanded Gemini IX, Apollo 10 (which conducted the first ever LOR), and Apollo-Soyuz.



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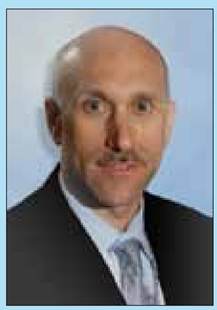

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National Security Space Access and the Space Elevator

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Will the US need to maintain a back-up capability to access space for national security space (NSS) assets after the construction of a space elevator (SE)? This question is important due to long term planning needed for current launch programs. The lower cost-to-orbit and design options allowed by an SE will make it the primary means to access space. But, due to the importance of space assets in national security, alternate means to access space may be required to ensure the ability to replenish satellites as needed should the SE route to orbit be closed for any reason.

The US Air Force's current family of evolved expendable launch vehicles (EELV) can continue in production and be used as a back-up for NSS missions. How long would these manufacturing lines need to remain open after construction of the SE? A short examination of the Titan/Atlas transition to EELV will illustrate spacelift options once the SE is constructed. Current launch requirements for NSS will be examined and compared against spacelift needs in the SE era.

Space Elevator Becomes Primary Means to Access Space

The SE is envisioned as a carbon nanotube tether one meter wide and 100,000 kilometers long stretching from the surface of the Earth out to geosynchronous orbit (GEO) and beyond to a counterweight. The mass of the 800-ton tether is balanced at the center point at GEO and centripetal force balances out the structure. Earth's gravity pulls the earth-side tether to the surface while the counterweight serves to pull outward. Laser-powered climbers depart the Earth's surface from a floating platform, probably based in the Pacific Ocean. These climbers arrive in GEO about five days later to discharge their material and personnel payloads. From there, a space logistic network would position the new assets to their assigned orbits or send it on its way out of Earth orbit, if required. The SE is an elegant solution to the question of how to provide cheap, reliable access to space.

With access to space just about as easy as stepping onto an elevator car, mankind will see an explosion in the use of space in near Earth orbit. Legacy missions will expand and new missions will come on line—solar power generation from space being the newest mission likely to have the greatest short-term impact. Even as a solid space infrastructure is established in Earth orbit, nations, corporate entities, and individuals will look outward to the solar system and the riches waiting to be claimed. But, before looking too far ahead, a look at the threats facing the US and its reliance on the SE to access space is in order.

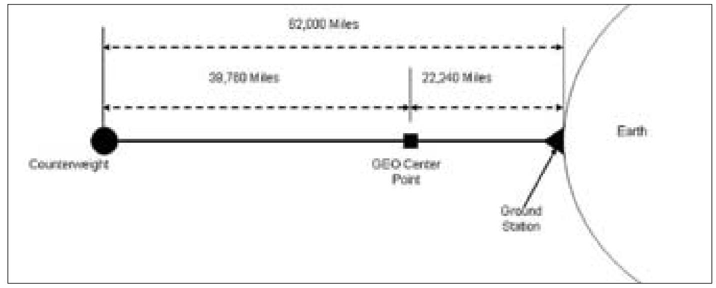

Figure 1. Space elevator basic layout.

National Security Space Definition

There is something more important than the ultimate weapon. That is the ultimate position—the position of total control over Earth that lies somewhere out in space. That is … the distant future, though not so distant as we may have thought. Whoever gains that ultimate position gains control, total control, over the Earth, for the purposes of tyranny or for the service of freedom.[1] ~ Lyndon B. Johnson, 1958

Traditional US NSS services can be divided into positioning, navigation, and timing (PNT), communications, and earth observation.[2] PNT provides "accurate location and time of reference in support of strategic, operational, and tactical operations."[3] "The current US satellite-based PNT architecture consists of a 24-satellite global positioning system (GPS) constellation operating in six different orbital planes in medium Earth orbit, approximately 20,200 kilometers from the Earth."[4] Communications include all manner of links used for unclassified and secure data and voice paths around the world. Earth observation includes the families of "reconnaissance, missile warning and defense, and weather monitoring" programs. An array of classified satellite programs provides important operational capabilities.[5] In short, NSS assets in orbit provide all critical space services for the US military and other national security agencies.

In the SE era, NSS services may expand to include remote power generation and transmission and spotlights from space. Building a SE suddenly makes many projects feasible. Power generation from orbit and on-call night-time illumination are but two of these missions.[6] Solar power is a free and inexhaustible energy supply. Using a SE, massive solar power collection and transmission stations could be constructed in GEO that could relieve and someday replace fossil fuel-based energy production. For the military, such stations could be developed to beam power down to fielded forces relieving these units from the need to bring fuel or generators into an undeveloped area of operations.[7] Similarly, on-call illumination from either mirrors or spotlights in orbit could be built to support military operations or emergency response.[8] These satellites would prove very useful in illuminating targeted areas or exposing enemy positions while leaving friendly forces shielded by darkness. In an emergency response situation, the same orbital illumination could be used to provide light while terrestrial power was restored or response personnel were in action. These are not the only missions which become feasible with the SE. Other future missions, led by the Department of Defense (DoD), may include asset protection and force projection. The need for such missions would depend on the threats faced by US assets, interests, and personnel in space.

Threats to Space Activities in the Space Elevator Era

Examining the current threat environment faced by the US and her allies is a good place to start when thinking about threats which may exist in era of the SE. The 2008 National Defense Strategy outlines the broad threats faced today. "The US, our allies, and our partners face a spectrum of challenges, including violent transnational extremist networks, hostile states armed with weapons of mass destruction, rising regional powers, emerging space and cyber threats, natural and pandemic disasters, and a growing competition for resources."[9] The current threats combined with "physical pressures—population, resource, energy, climatic, and environmental—could combine with rapid social, cultural, technological, and geopolitical change to create greater uncertainty."[10] The US confronts challenges faced in the international arena with a mix of "military, diplomatic, and economic means" in order to satisfy the nation's interests such as "protecting the nation and our allies from attack or coercion, promoting international security to reduce conflict and foster economic growth, and securing the global commons and with them access to the world markets and resources."[11] On-going threats, uncertainty in the future, and unchanging national interests indicate the environment in the near-term will, if anything, continue to offer a wide range of challenges.

The DoD's core responsibility is to defend the homeland "through an active layered defense … through deployments at sea, in the air, on land, and in space."[12] Another objective of the DoD is to deter attack. This is particularly important when considering space assets which are critical to the nation's economic and defense infrastructure. In order to deter attack, the US must "consider which non-lethal actions constitute an attack on our sovereignty, and which may require the use of force in response."[13] Is an attack on a communications satellite an act of war? How the US responds to the first incident will determine the likelihood of other entities attempting the same feat. With expanded reliance on space assets and resources with the SE, the role of the US securing strategic access to commons (i.e., space lanes of communication) may become essential, just as today the US "requires freedom of action in the global commons and strategic access to important regions of the world to meet national security needs."[14] NSS assets are critical for the DoD to perform its mission.

Threats to US interests in space in the era of the SE may very well mirror those threats faced today at sea, on the ground, or in air or space. But what of the SE itself—will it remain reliable enough for the US to rely as a sole means to access space?

Transition Periods and Guaranteed Access to Space

Spacelift is one of the operational functions of air and space power as assigned to the US Air Force.[15] "The Air Force is the DoD service responsible for operating US launch facilities"[16] to provide assured access to space. "Assured access to space is a key element of US national space policy and a foundation upon which US national security, civil, and commercial space activities depend."[17]

Does the US require redundant paths to access space? The example of the development of the Air Forces' EELV show a path the US has taken in developing and maintaining the means to access space. In the case of EELV, two entirely different families of launch vehicles were developed and then maintained—ensuring the US had redundant launch capabilities should a failure shut one of the systems down for an extended period of time.

The US has learned some hard lessons about relying on a single means to access space. The Challenger accident in 1986 shut down shuttle flights for two years, grounding both manned missions and NSS payloads—effectively eliminating "the ability to place the nation's highest priority satellites into orbit."[18] With NSS assets in orbit playing critical roles in everyday life and for every military operation, reliable access to space is essential. Plans to shift NSS payloads to the shuttle were scrapped, planned shuttle operations from Vandenberg AFB, California were scuttled and the unmanned expendable rockets returned to center stage as the US Air Force's means of providing assured access to space. Instead of the shuttle, NSS payloads would rely on legacy launch systems—Titan and Atlas—to get into orbit. The heavy lift Titan IV and medium lift Atlas II were derived from intercontinental ballistic missile designs and were very costly. The EELV program was conceived to build a new family of launch vehicles to replace the legacy systems and provide the same launch services at reduced cost.

EELV was envisioned to cut costs by streamlining production, simplifying processing for launch and by volume purchases as it provided services to both government and commercial customers. In the end, the commercial side of the business model never developed and the Air Force decided to maintain both the Atlas V and Delta IV vehicle families to ensure reliable, redundant means to access space. Boeing's Delta IV and Lockheed Martin's Atlas V rockets both offer NSS payloads reliable access to space with very few single points of failure between them – ensuring an anomaly with one family will most likely not shut down the other.[19] In the case of EELV, the US has maintained redundant, reliable launch capabilities to ensure NSS payloads have assured access to space.

Which path will the US choose once the SE is built—an overlap of redundant capabilities to access space or jumping feet first into complete reliance on the SE to get to orbit? The answer will be driven by the environment in which the SE will be built and operated.

Scenario Forecasting – Space Elevator as Sole Access to Space

It will not do to leave a live dragon out of your plans if you live near one.
~J.R.R. Tolkien

Will the SE be able to provide 100 percent guaranteed access to space to meet the needs of NSS? In the SE era there will likely remain the same adversaries the US faces today around the globe: nation-states, non-state actors, and acts of nature. Any of these challenges could easily limit access as the SE transitions to the center of gravity for national and military access to space. Destruction of or disabling the SE would severely limit responses to crisis in space if no other means to orbit were available. The need for a back-up means of accessing space in the era of the SE can be framed by two factors; control of the SE and threats to the SE. For this discussion, the US controls the SE but the threat environment is either low or high based on the threats faced by the SE.

In the first scenario, "SE as single path," the SE operates in a low threat environment and is controlled by the US. The US has constructed and now controls the SE, providing assured access to space for all for all missions ranging from commercial ventures, scientific and civil endeavors, military and NSS missions. With weight restrictions and design restrictions lifted by the advent of the SE, NSS missions are now performed by massive platforms in or beyond geosynchronous orbit. Power generation from orbit has joined communications, Earth observation, and PNT as critical NSS missions. From the firm base of access provided by the SE, the US sees an explosion of commerce in orbit and beyond. NSS provides the security needed by the US while humanity moves out into the solar system. There is no need for alternate access to space. The last 12 production models of expendable launch vehicles are turned over to museums after being kept in storage for many years.

A future where the US faces a high threat environment and has control of the SE defines the "redundant paths" scenario. While the SE is used as the primary means to access space for civil, commercial, and NSS missions, there is enough of a threat on the ground and in orbit to justify the need to maintain an alternate means to access space. Low cost commercial ventures such as SpaceX provide a reliable means to boost payloads into orbit. EELV remains in production as a government sponsored back-up, albeit scaled down to a single family of vehicles produced by ULA. Production facilities in orbit are planned for NSS assets, alleviating the need to build and lift the payloads to orbit once and for all. Until that time, the back-up means to access space with expendable launch vehicles will remain.

Although the "SE as single path" scenario would be the most desirable, the "redundant paths" scenario would appear to be the most likely future scenario over the next 20-30 years. Threats to US interests in orbit and on the ground will likely continue at the current level or grow as more nations gain capabilities to strike US assets in orbit. Also, the SE will allow major increases in activity in orbit. Greater increases in activity mean more assets to track and the greater need to protect assets already in place even against non-military threats. As the US has been painfully taught, an asset does not have to be of military origin to have disastrous impacts—that is, commercial airliners turned into fuel-laden guided missiles.

Projected NSS Needs

NSS missions are usually critical to national security, and continued service is a very high priority.[20]
~ National Security Space Launch Report, 2006

The current method of launching NSS assets aboard EELV has been examined and found to meet "NSS needs through 2020 and beyond."[21] This assumes no new "scientific developments that might lead to fielding a radical breakthrough in space launch during the next 15 years" and "basic rocketry principles, use of chemically derived thrust, and multiple expendable stages seem certain to remain the design choice for operational space launch vehicles" through 2020.[22] Current launch capabilities meet projected launch needs through 2020 at the rough rate of 10 launches per year.[23] The current manifest of NSS missions provides for the legacy missions of PNT, communications, and Earth observation.

A SE could easily handle the current planned NSS mission load and more. With the construction of the SE, I assume the number of NSS platforms will increase in both size and number as ease of access lowers both launch costs and design constraints for legacy missions. Also, the advent of the SE will usher in an era of new NSS missions including remote power generation and transmission and spotlights from space. Other future missions, led by the DoD, may include asset protection in orbit and beyond and force projection through space. It is impossible at this stage to accurately project the number of NSS 'launches' required once the SE comes on-line. But, with just one climber leaving earth per day, 365 lift opportunities would be available. Even with the spread of solar power from orbit and the massive construction projects entailed with this effort, NSS missions would still remain far less than 50 percent of SE traffic (better than today's predictions).

Summary

The US is a space-faring nation with vital national interests protected and enabled by NSS assets. Given the criticality of space to US national security, there must remain the means to access space by redundant methods. The SE will provide one of these paths. In the near term, the most likely alternate means to access space for NSS missions will remain as expendable launch vehicles. Current government programs, such as EELV or commercial ventures, can provide the lift capability for NSS missions. The likely choice for redundant NSS lift capability would be one or more of the vehicles in the EELV program will likely remain the back-up of choice for NSS missions. This redundancy will be required until no longer needed to assure NSS mission access to orbit.

Notes:

1 General Michael T. Moseley, USAF, chief of staff, Space Operations – Air Force Doctrine Document (AFDD) 2-2, 27 November 2006, 1.

2 Office of the Secretary of Defense (OSD), National Security Space

Launch Report, RAND National Defense Research Institute, Arlington, Virginia, 2006, 2.

[3] General John P. Jumper, USAF, chief of staff, AFDD1, 17 November 2003, 57.

[4] OSD, National Security Space Launch Report, 2.

[5] Ibid.

[6] Bradley Edwards, "White Paper – Military Applications of the Space Elevator," (Fairmont, West Virginia: Institute for Scientific Research, 2003), 2.

[7] Ibid. 5.

[8] Ibid. 3.

[9] Robert M Gates, secretary of defense, National Defense Strategy, June 2008, 1.

[10] Ibid, 4.

[11] Ibid, 6.

[12] Ibid, 6.

[13] Ibid, 12.

[14] Ibid, 16.

[15] General John P. Jumper, AFDD1, 52.

[16] Ibid, 52.

[17] Ibid, 52.

[18] Samuel A. Greaves, "The Evolved Expendable Launch Vehicle (EELV) Acquisition and Combat Capability," Air Command and Staff College, Maxwell AFB, Alabama, March 1997.

[19] Boeing and Lockheed Martin have recently combined their Delta IV and Atlas V operations under United Launch Alliance as a money-saving measure.

[20] OSD, National Security Space Launch Report,11.

[21] Ibid., xix.

[22] Ibid., xiii.

[23] Ibid., 6.

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Major Kent has served in a variety of leadership positions involving intelligence, engineering, space operations, launch operations, system engineering, space acquisition, and program integration. In 1996, he was certified as an intelligence operations officer at Goodfellow AFB, Texas after completing the year-long Intelligence Fundamentals and Operations Officer course. He went on to work in Imagery Production and Operations at the National Air and Space Intelligence Center at Wright-Patterson AFB, Ohio. Major Kent then served as chief of booster and facility operations and as the mission support flight commander with the 2d Space Launch Squadron for the Titan IVB, Titan II, and Atlas II spacelift missions from 1998 to 2002. From 2002 through 2006 he served in many roles including senior flight commander and director of engineering for Secretary of the Air Force-directed operations. Major Kent attended Air Command and Staff College in residence in 2006 and arrived at Los Angeles AFB, California to assume his current duties in the Launch and Range Systems Wing in 2007. Major Kent has been selected for promotion to lieutenant colonel.

Responsive Space for Europe

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The Setting for a European Approach to Responsive Space

Europe has adopted a broad understanding of the concept of security comprising: internal security threats such as terrorism and organized crime; environmental threats such as deforestation, climate change; natural disasters such as land slides, earthquakes, and tsunamis; and external security threats including military aggression in the near abroad. Based on these threats, Europe needs operational, responsive, and flexible instruments with which to act. Given the broad range of potential threats Europe could face, it has to meet a broad range of user requirements for the prevention of and response to any of these threats.

Several European Union (EU) research initiatives have looked into how space as an instrument can support security policy and missions both internally and externally. Some of the studies include: the EU's Framework Programme (FP) for Research and Technological Development, the Security Panel of Experts and its subsequent report, the Group of Personalities for Security Research, the European Security Research Advisory Board, and the European Security and Research Innovation Forum.[1] They have given insights into existing capabilities and the improvements needed both from a strategic, policy-oriented, as well as a technical standpoint.

Additionally, several think tanks have evaluated European approaches to security. These include the Belgian Royal Institute for International Relations initiative, which proposed a European security concept for the 21st century, and the EU Institute for Security Studies that put forward suggestions for Europe's ambitions for European defense in 2020. While not directly dealing with the use of space applications in the provision of security, these attempts have aimed to answer questions, which are also raised in the context of responsive space. This includes the EU's relationship with North Atlantic Treaty Organization and the question of parliamentary oversight over the EU Common Security and Defence Policy.[2]

In this setting, the European Space Agency (ESA) is exploring new concepts in the realm of space and security consistent with its convention, the European Space Policy (ESP), and the recent resolutions adopted by the Space Council and by the ESA Council at ministerial level.[3] One of these is Global Integrated Architecture for iNovative Utilisation of space for Security (GIANUS), which aims at meeting user needs particularly with an eye to the increased dependence of the EU on space assets, the need for tools in the operational theatres and the increased opportunities arising from GIANUS is currently designed to contain a responsive element.

Why does Europe need 'Responsive Space'?

Considering the topics that are currently under discussion in the context of Europe and space policy, which includes workshop and conference topics, studies, articles, and presentations, several recurring issues for Europe have been identified. There are new emerging technology and operational capability requirements. The transition from demonstration to operations must also be addressed. Exploiting synergies between military and civil applications continues to be a challenge. Furthermore, users should be involved in the research and development process.

There are also issues related to data policy. This includes standardization and regulation, countering the EU's islands of data by establishing standardization of data to improve data sharing and protection of sensitive data while at the same time not hindering data sharing across borders and user communities. There is also a need for a more integrated approach in terms of integrating European and national assets, capabilities and services, such as integrating satellite communications (SATCOM), satellite navigation (SATNAV) systems and Earth observation (EO), and integrating space applications with other terrestrial applications.

Responsive Space (RS) is a concept that addresses all these issue-areas in a holistic manner (figure 1). Its main objective is to provide more flexible and more affordable space applications to users. RS capabilities can augment/surge existing capabilities, fill unanticipated gaps in capabilities, and due to fast development times, exploit new technical/operational innovations. RS could include user requirements that are formulated and successfully demonstrated in FP projects and put them into practice. In this way it would address the transition from demonstration to operation and enhance user involvement in the research and development process. Given that user needs are diverse, RS draws upon an integrated approach and combines SATCOM, SATNAV and EO assets and applications, as well as incorporating space applications into comprehensive concepts with terrestrial applications. Since RS relies on all existing assets, it will also need to establish a data policy thereby addressing the issue of standardization and protection of sensitive data with an eye to increased data sharing, while at the same time trying not to pose trade barriers.

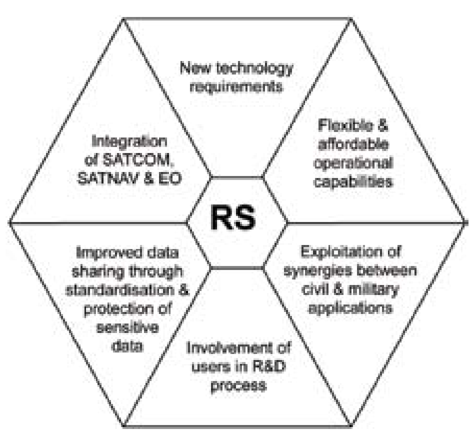

Figure 1. A holistic approach to responsive space.

Unlike most military systems, such as tanks and fighter aircraft, satellite systems provide services for commercial, civil, government, and military activities. Space capabilities can be used for military operations, but it can also be used to support crisis response, environmental disasters, agriculture development, logistics, and countless other applications. In France, satellite imagery is used to optimize irrigation and productivity of the agriculture industry. These same capabilities can be used to improve agriculture and for security activities such as counter-narcotic missions to find poppy fields in Afghanistan. Furthermore, space-based services can be used for commercial customers, national government, and military users, as well as being shared with allies, coalition partners, and non-government organizations such as the United Nations and the Red Cross. Moreover, these services can also be sold in the global market. Developing RS would benefit many users of space.

The space security environment has also changed significantly in recent years. Advances in technology, development of small satellites and advances in commercial capabilities have reduced the cost of entry to the point were there are many new space-faring nations. A more crowded environment asks for more responsible use. Unfortunately, not all of them are responsible users of space. One example is the anti-satellite weapon test in 2007, which was the biggest debris-creating event on record. Figure 2 shows the debris cloud created by the event as well as a prediction of debris decay. As of 10 June 2010, only 50 of the 2,691 pieces of debris (that can be tracked) have decayed from Earth orbit.[4] Debris from this event will continue to threaten satellites from many nations for more than a hundred years. Additionally, it can be concluded from US studies, war games, and experiences that Europe will also need to be able to rapidly reconstitute lost capabilities, to respond to unforeseen or episodic events and to enhance survivability and deterrence of space systems. RS capabilities can address some of these increasing security risks to European space systems.

RS is neither a simple armament approach nor is it a futuristic technology-push model. It is a concept whose time for more detailed investigation has come and for which appropriate policy perspectives must be developed, now. Its benefits for European civilian and security related issue areas are abundant and should be given detailed and thorough consideration.

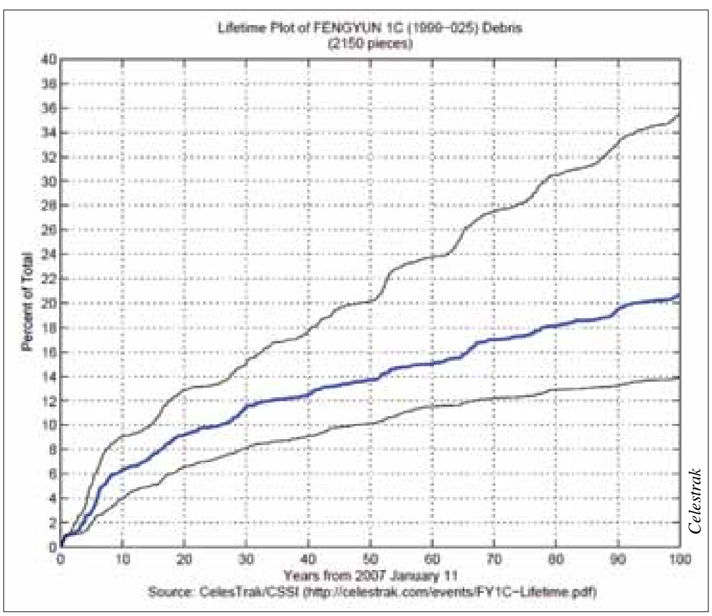

Figure 2. Model of the 2007 debris event.[5]

Conceptual Considerations for a European Approach

While the need for responsive space services is unambiguously felt, as can be seen from demonstrations that are part of the FP projects, EU external relations missions such as EU Forces Tchad (EUFOR Tchad/RCA) and the current EU Atalanta Naval Forces (EU ATALANTA NavFor) counter-piracy mission off the Somalian coast,[6] "responsiveness" is still not a clearly defined and understood concept. "Responsiveness" can be defined as the ability to address needs in a timely manner. A system is commonly referred to as "responsive" if it can rapidly react to inputs or events or if it can efficiently cope with changes and uncertainty in its environment.

The main elements of "responsiveness" are: "flexibility (timely development and the ability to modernize), low costs, and rapid launches. Hence, a thorough understanding of the schedule structure, the various activities within the space industry (design, production, reviews, integration, testing, etc.) as well as the total-life-cycle cost (including acquisition, operation, and maintenance costs) is required.[7]

Another complementary way of analyzing responsiveness is to see it from the perspectives of the different stakeholders: end-users, local customers, and suppliers. Additionally, responsiveness depends on three different levers. The first is design and architectural choices of a system, which is determined by the complexity of a system, the degree of use of identical units and repetitive tasks, modularity, plug and play, and standardization of interfaces. Second, launch levers, which includes the launch vehicles and range. Thirdly, are the soft levers of responsiveness, such as the selection process, design reviews, and acquisition policies.

The US Approach

In 2007, the US Congress asked the Department of Defense (DoD) to formulate a plan to establish operational responsive space (ORS) and authorized DoD to establish an ORS Office.[8] The ORS Office's mission is to develop low-cost, rapid reaction payloads, buses, spacelift, and launch control capabilities. Additionally, to coordinate and execute ORS efforts across the DoD. ORS in turn was defined as "[a]ssured space power focused on timely satisfaction of joint force commanders' (JFC) needs."[9]

The US is currently the only space-faring nation that is developing an RS capability. The US ORS concept originates from the military. When proposing a European approach to this matter, the US experience can serve as a guiding theme, providing a case study on how responsive space can be developed. Given that the US and Europe differ in terms of the objectives of their space policies, their threat perceptions and, consequently, their understanding of the concept of security, the US ORS can only serve as an example and not as a prototype for Europe to emulate.

Increasing reliance on space applications and emerging global challenges and threats have placed new demands on US space capabilities, which were designed during the Cold War to counter national security threats, which were traditional external security threats. Those threats have now changed. As an increasing number of nations have developed space programs, the space environment is increasingly perceived as non-transparent and contested. Today, the JFC continues to be one of the main users of US space capabilities. However, the changed threat environment, is driving new requirements. In contrast to the Cold War era, the military is no longer the sole and main user. Commercial satellites are increasingly providing vital space applications such as in the provision of security, emergency management and climate change. In the context of greater dependence on space applications, satellites are increasingly perceived as critical infrastructures, which are threatened by both intended and non-intended interference.

The DoD inaugurated the ORS Office in 2007, which has been tasked to coordinate the development of hardware as well as the development of the concept across the agencies involved. The US ORS concept aims to satisfy the needs of the JFC by developing the enablers to allow for rapid development, deployment and operation of space assets to support operational requirements. The US ORS program follows a three-tiered strategy: (1) rapid exploitation of existing capabilities; (2) use of existing technologies and capabilities to replenish, augment and reconstitute; and (3) development of new technologies and capabilities to replenish, augment and reconstitute.[10]

Additionally, the US is developing several programs for the development of responsive launch, such as Responsive Access, Small Cargo, Affordable Launch (RASCAL), Force Application and Launch from CONUS (FALCON), Evolved Expendable Launch Vehicle (EELV) program, United Launch Initiative, and the Affordable Responsive Spacelift (ARES). The US is also researching responsive payloads and buses as part of its Tactical Satellite (TacSat) program, an Air Force initiative that uses small spacecraft.

Elements of a Roadmap for Europe

The ESP is currently largely driven by civilian considerations but faces growing security-related demands. Given Europe's broad understanding of the concept of security, there is a need for instruments to support a wide variety of European security and safety missions (e.g., external security actions, border surveillance, maritime surveillance, anti-piracy, narco-trafficking, emergency response to natural disasters, etc.). A European concept for RS would provide these instruments. In contrast to the US ORS concept, which deals solely with the military national security requirements, Europe's RS will need to develop a system to take both civil and military requirements into account.

The current degree of readiness of the European industry to become involved in RS is hard to assess. European industry has been involved in many demonstrations as part of the FP projects. Their feedback shows that they are ready to provide many of the requested technological requirements and are sometimes even far ahead of the outcomes of EU research projects. What has been lacking so far is the political will to encourage the industry to take the necessary future steps towards more integrated, flexible, and affordable space applications for Europe. Specifically, it is the lack of political direction for European, rather than national, solutions. Quite often in the past, one nation (acting alone or together with several like-minded or interested other European states) took up a topic and put it on the agenda.

The institutional architecture supporting RS in Europe will need to look different than the one the US has chosen. To empower one institutional actor to steer the RS seems to be necessary in order to ensure oversight and comprehensiveness, avoid duplication of efforts and guarantee that all stakeholders share the same understanding of RS. Currently, there does not seem to be an existing European institutional actor suited for this purpose. Hence, one element of a European RS could be to establish a dedicated institutional actor for this purpose. A EU agency (which could be called "The Steering Agency for Responsive Space [STARS]") could be tasked to lead, steer and coordinate RS in Europe.

Based on the above conceptual considerations and the US ORS experience, elements of a roadmap for RS in Europe have been identified. Basic problems that have to be tackled and answered before being able to formulate a European approach to RS are highlighted below. More detailed elaboration on (1) institutional and architectural questions, (2) legal, organisational and managerial challenges, (3) time, (4) cost, (5) secure data policy, and (6) the timeframe for the establishment of a European RS can be found in the European Space Policy Institute's study "Responsive Space—Elements of a Roadmap for Europe."[11]

The first step towards creating RS is to conduct a thorough assessment of current space assets both at European and national levels. This status report should enumerate existing capabilities and include a thorough gap analysis. The Joint Research Centre has already conducted some first studies in the context of space applications for maritime security.[12] It conducted benchmarking activities as part of the FP 5 Detection and Classification of Marine Traffic from Space project and, as part of the commission's call for an integrated maritime policy, it evaluated existing maritime surveillance systems at national level and compiled a comprehensive report in a document entitled "Integrated Maritime Policy for the EU: Working Document III—On Maritime Surveillance Systems."[13] Additionally, a gap analysis should answer the following questions: Who are the users? What do they need? What do we have? In particular, how would Tactical Imagery Exploitation System, Multinational Space-based Imaging System, Galileo, and Global Monitoring for Environment and Security contribute to RS? What is missing? The gap analysis could draw on FP and national research. The resulting needs matrix should be subdivided into short-, mid-, and long-term requirements in line with the three-tiered approach.

In addition to a status report on existing space capabilities, lessons learned and demonstration results of research and development projects at both European and national level should be taken as building blocks for Tier 2 and Tier 3 developments. By compiling both of these, the stakeholders involved could be identified. From the very start, these should be included in the development process of a European responsive space as to agree on the definition for RS. Once users have been identified, a requirements matrix should be established. The matrix should be used to identify a way to feed-in the different user requirements for the RS architecture and development process.

Moreover, there is a need to develop the political will to use the capabilities that are available. Outreach activities showing users what is possible and presenting the case in all possible forums could help in fostering the necessary political will. In the future, military requirements can be compiled by the European Defence Agency and civilian ones by the European Commission (EC) supported by the council. Engagement and dialogue with users should be increased. The establishment of a user-exchange mechanism would be a step in this direction.

Access to systems in the event of a crisis is of utmost importance. In this context, ownership is crucial. However, guarantee-ing that systems remain on the European side can also be achieved through the use of multinational missions or by signing treaties and agreements to cover these cases. US experience has shown that it is particularly important to establish an understanding of RS with all these stakeholders. In the US, the ORS Office is responsible for this. As ESA is a technology development agency and the EC is limited to engaging in space matters only upon member states consent (shared competence), it seems difficult to entrust an existing actor with this task. Thus, the proposed agency would take this up.

RS is expected to create a whole new paradigm in the space field that, from a developer's perspective, requires specific technologies, and new development and implementation approaches. As many new enabling technologies need to be investigated, a system for long-term research and development efforts to foresee future requirements needs to be found. Both academia and think tanks can be involved in this effort. Industry and satellite operators should also provide their input. RS will require adaptation of field operations, decision-making processes, and of activation or allocation procedures. This would go hand-in-hand with adaptation of the industry value chain.

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Colonel Single's operational experience includes ICBM, Space and Air and Space Operations Center weapon systems. He served on Missile Combat Crew and was the chief of electronic warfare officer training at the 90th Missile Wing. In 2000, he attended AFIT and was subsequently selected as one of two Air Force officers to be the first ever service chief interns at Defense Advanced Research Projects Agency. He subsequently served as the chief test analyst at the 17th Test Squadron, followed by the chief of Theater Support, Weapons, and Tactics Branch, at Air Force Space Command Headquarters.

Ms. Nina-Louisa Remuss (BA, European Studies, University of Maastricht [The Netherlands]; MLitt, International Security Studies, University of St. Andrews [United Kingdom]) is associate fellow of the European Space Policy Institute (ESPI), Vienna, Austria. She is currently leader of a study on the contribution of space applications in the fight against piracy. At the same time she is co-editor of "Humans in Outer Space–Interdisciplinary Perspectives," which will be published in the series Studies in Space Policy at Springer Vienna NewYork. Since July 2008 she has been contributing to ESPI's Research Programme Space and Security. She co-authored a study on Europe's role in the peaceful-uses of outer space debate, led a study and a related workshop on the contribution of space applications to internal security which was conducted under the auspices of the Czech European Union Council Presidency. She also published a policy paper on the vulnerability of space assets in the context of terrorist intended harmful interferences. Ms Remuss has contributed numerous articles and papers to leading journals in the field and is regularly invited to speak at conferences in Europe and the US.

Reliable and Affordable Falcon Commercial Launch Vehicles for Operationally Responsive Launch

Mr. Mike Bender
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Washington DC

Policy and Congressional Direction

The US government has issued very clear policy regarding its use of commercial space capabilities and services. The National Space Policy, dated 31 August 2006, contained in National Security Presidential Directive-49 (NSPD-49) states: "Departments and agencies shall use US commercial space capabilities and services to the maximum practical extent; purchase commercial capabilities and services when they are available in the commercial marketplace and meet US government requirements; and modify commercially available capabilities and services to meet those US government requirements when the modification is cost effective."

The US government's policy is also clear about the need for operationally responsive space launch. NSPD-40 on US Space Transportation Policy, dated 21 December 2004, states: "The secretary of defense, in coordination with the director of central intelligence, shall develop the requirements and concept of operations for launch vehicles, infrastructure, and spacecraft to provide operationally responsive access to and use of space to support national security, including the ability to provide critical space capabilities in the event of a failure of launch or on-orbit capabilities; and identify the key modifications to space launch, spacecraft, or ground operations capabilities that will be required to implement an operationally responsive space launch capability."

On 16 October 2009, General C. Robert Kehler, commander of Air Force Space Command (AFSPC), in his Interim Guidance For Small Launch Vehicles Memorandum, wrote: "AFSPC must begin preparations for the emerging operationally responsive space (ORS) mission which will require highly reliable and *cost-effective small launch capability*." In the John Warner National Defense Authorization Act for fiscal year 2007, Congress provided the fiscal goal for cost-effective small launch: "To the maximum extent practicable, the procurement unit cost of a launch vehicle procured by the ORS Office for launch to low Earth orbit (LEO) should not exceed $20 million."

Space Exploration Technologies Corporation

Highly reliable, low-cost space transportation is the singular goal of commercial launch vehicle manufacturer and launch services provider Space Exploration Technologies Corporation (SpaceX). Founded in 2002 and now employing over 900 people, SpaceX is the first commercial company to privately develop and successfully launch a liquid-fueled rocket into orbit. Design simplicity and hardware commonality across SpaceX's family of Falcon launch vehicles (figure 1) result in substantial improvements in system reliability and affordability.

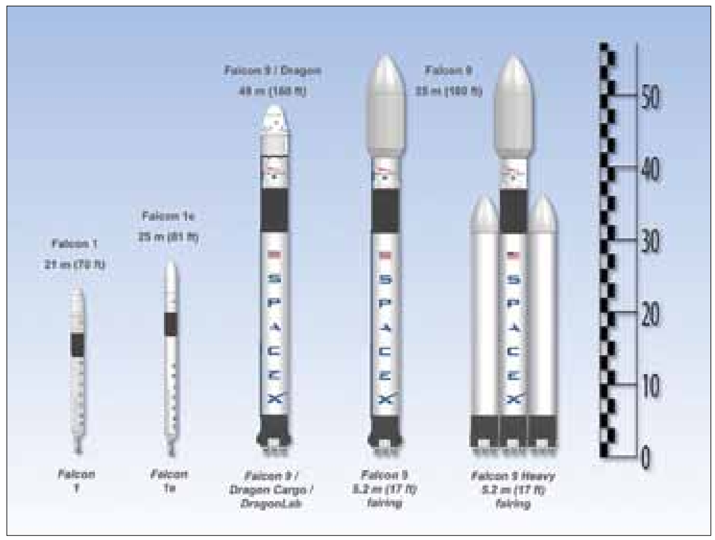

Figure 1. SpaceX's Falcon family of launch vehicles.

The Falcon 1 small launch vehicle achieved operational status in 2008 and is currently being enhanced to the Falcon 1e to increase payload capability to LEO from over 400 kilogram (kg) to 1,000 kg. As discussed in the following pages, Falcon 1 missions conducted in 2007 and 2008 demonstrated several enablers for operational responsive launch. SpaceX will work with the ORS Office to achieve the six-day call-up to launch objective for ORS with the Falcon 1e. The standard commercial launch services price for a Falcon 1e is $10.9 million, well under the $20 million not-to-exceed goal provided by Congress.

The Falcon 9 medium-to-intermediate-lift class launch vehicle will deliver over 10,000 kg to LEO and 4,500 kg to geostationary transfer orbit (GTO), and is designed to National Aeronautics and Space Administration's stringent man-rating standards, evidence of the fact that SpaceX holds reliability paramount. Falcon 9 will lift Dragon, SpaceX's free-flying, reusable spacecraft/capsule, or—when outfitted with a 5.2-m-diameter composite fairing—launch government or commercial satellites. The first launch of the Falcon 9/Dragon will occur in 2010. SpaceX currently has over 30 flights of Falcon 1e and Falcon 9 manifested through 2015. The standard commercial launch services price for a Falcon 9 is $45.8 million to $51.5 million depending on the mission and spacecraft weight. The above Falcon 1e and Falcon 9 prices are valid through 30 April 2010. Further details, including the latest launch services pricing and payload users' guides are available on SpaceX's web site.

The Falcon 9 Heavy is SpaceX's entry into the heavy-lift launch vehicle category. Capable of lifting over 32,000 kg to LEO and over 19,000 kg to GTO, the Falcon 9 Heavy can meet the launch requirements for the largest national security and commercial payloads. The Falcon 9 Heavy consists of a standard Falcon 9 with two additional Falcon 9 first stages, effectively serving as liquid strap-on boosters. The first Falcon 9 Heavy launch will occur approximately 24 to 30 months after authority to proceed from an inaugural customer.

SpaceX's headquarters in Hawthorne, California, is a 550,000-sq-ft facility that contains modern office, manufacturing, and production space. The company's 300-acre Rocket Development Facility in McGregor, Texas, is used for structural and propulsion testing including development, qualification, and acceptance.

SpaceX has an operational launch site for Falcon 1 on Omelek Island (figure 2), Kwajalein Atoll, about 2,500 miles southwest of Hawaii, and is in the design phase of upgrading the site to accommodate Falcon 9 launches for superior performance to GTO, as well as high-inclination orbits. The initial Falcon 9 launch site is Space Launch Complex 40 (SLC-40), former home of the Titan IV heavy-lift rockets, on Cape Canaveral AFS (CCAFS), Florida. This launch site can also accommodate Falcon 9 Heavy missions. SpaceX plans to establish a launch facility at Vandenberg AFB (VAFB) in central California to meet customer needs for polar and sun-synchronous capability. Space's baseline plan is to replicate the Falcon 9 CCAFS facilities at Kwajalein and VAFB, thereby retiring significant risk to customers by establishing launch site redundancy for every range of azimuth.

Figure 2. SpaceX launch facilities on Omelek Island Falcon 1/1e small launch vehicle.

On 28 September 2008, SpaceX made history when its Falcon 1, designed and manufactured by SpaceX, became the first privately developed liquid-fueled rocket to orbit the Earth (figure 3). The design, development, build, test, and successful launch of the Falcon 1 in SpaceX's first six years of existence represent a significant accomplishment. It included "clean sheet" development of all propulsion, structures and avionics; fully qualifying the vehicle, ground and launch support systems; and certifying a flight termination system (FTS) with multiple Federal Ranges.

Figure 3. SpaceX Falcon 1, 28 September 2008.

Falcon 1 is a two-stage launch vehicle powered by liquid oxygen (LOX) and rocket-grade kerosene (RP-1). SpaceX minimized the number of stages to minimize separation events, which are one of the primary causes of failures in launch vehicles. The first stage has high mass efficiency aluminum tanks that use pressure-assisted stabilization in flight. A single regeneratively cooled Merlin 1C engine powers the Falcon 1 first stage with a sea-level thrust of 78,000 pound force (lbf). The Merlin engine is pressure-fed on a gas generator cycle using an efficient turbopump propellant feed system. The turbopump employs the simplest possible design—one shaft drives both the LOX and RP-1—for high reliability. The upper stage is pressure-fed and is constructed of aluminum lithium. The upper stage engine, Kestrel, is fully qualified (with over 16,600 seconds of testing) and is capable of up to three restarts (depending on the mission). The Kestrel restart capability was successfully demonstrated during the 28 September 2008 flight and again on a subsequent flight 13 July 2009. The Falcon 1 avionics suite comprises flight-proven components including an inertial measurement unit (IMU), a ruggedized flight computer with analog and digital input and output, a 14-channel global positioning system (GPS) receiver, S-band telemetry and video downlink systems, a C-band transponder for tracking, and an Ethernet bus for connectivity. The GPS receiver is flown for navigation updates to support the IMU. The guidance, navigation, and control system also includes a controller for tank pressure regulation, batteries, and power distribution. The bi-conic, aluminum payload fairing on Falcon 1 is a clamshell design that separates via an explosive marmon clamp band system and gas pushers.

Enhancements to the Falcon 1 to increase performance and capability are being internally funded. The Block 2 version of Falcon 1, known as the Falcon 1e, comes with a larger fairing and increased payload volume, as shown in figure 4. The first flight of Falcon 1e, which is SpaceX's baseline small launch vehicle going forward, will occur in early 2011.

The Falcon 1e uses the Merlin 1D engine, a higher performance follow-on to the flight-proven Merlin 1C. Increased chamber pressure permits the sea-level thrust to be increased to 120,000 lbf, and the Merlin 1D offers a greater first-stage

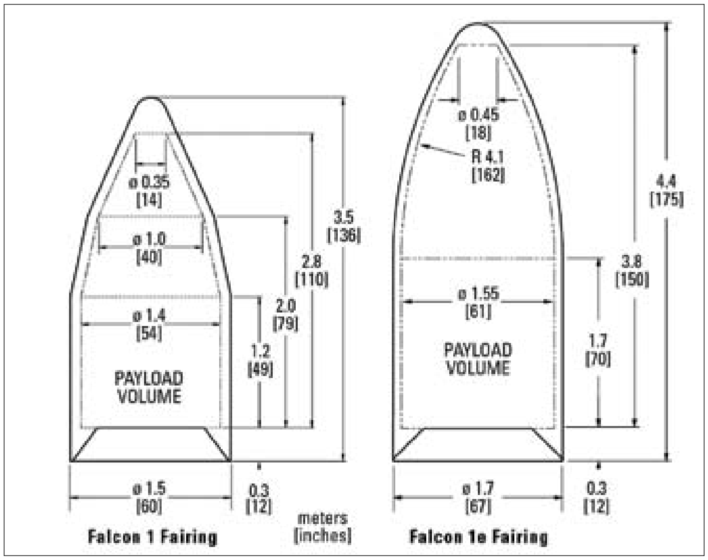

Figure 4. SpaceX Falcon 1 and Falcon 1e payload fairing dimensions.

nozzle expansion ratio and higher specific impulse compared to those of the Merlin 1C engine. This third-generation Merlin engine also has continuous throttle capability. Additionally, numerous improvements in reliability, producibility, and operability are being incorporated, all while decreasing part count. Finally, because this engine is common to the Falcon 9 launch vehicle which uses nine Merlin engines on its first stage and one Merlin engine on it second stage, a significant amount of engine flight heritage data will be collected in a relatively few number of missions. The first-stage tank is being elongated and strengthened to support the increased axial thrust loads and higher propellant consumption needs of the engine upgrade.

To further enhance reliability, the Falcon 1/1e vehicles are held down on the launch pad for three seconds between first-stage engine ignition and liftoff so that engine health and nominal operation can be confirmed. An automatic safe shut-down occurs if any off-nominal conditions are detected. This feature proved invaluable for the initial Falcon 1 demonstration missions when vehicle sensor readings were outside their nominal ranges, requiring the launch vehicle to safely abort seconds before liftoff. Both the payload and the launch vehicle were saved from executing under off-nominal flight conditions. Even after a hot-fire abort, the vehicle and launch team can recycle in as little as 34 minutes and lift off successfully.

Operationally Responsive Launch

SpaceX has deliberately designed its launch vehicle systems so that launch site operations are simple, quick, and efficient. This approach is critical because quality and mission success are both greatly increased by reducing or eliminating the amount of processing required under less than ideal conditions. Costs are reduced by minimizing the number of personnel required at the launch site—and the necessary duration of their stay. In addition, flight rate is increased by reducing the on-pad time for each launch. Scheduling range time is simplified and conflicts reduced by reducing and compressing the testing requiring range assets. For all these reasons, the Falcon 1/1e vehicles were designed to require relatively little launch site infrastructure, and are processed very quickly from arrival at the site to liftoff. For example, once the payload arrives, attachment and fairing encapsulation can be completed in less than 24 hours. The following paragraphs discuss ORS enablers demonstrated by SpaceX and progress towards the six-day call-up to launch objective for ORS.

In February 2008, the ORS Office contracted with SpaceX to participate in the Jumpstart mission. The objectives of this mission were to demonstrate several ORS enablers, such as streamlined payload processing to enable a rapid call up to launch, low-cost access to orbit for ORS-class vehicles, and software encryption. The mission also established a preliminary framework for responsive processes to include rapid contracting, procedure development, and spacecraft development, integration and test.

SpaceX's effort included the manifest planning, integration, and testing of several payloads, with the identification of the primary payload revealed just two weeks prior to launch on a Falcon 1. The three candidates for primary payload were an Air Force Research Laboratory (AFRL) plug and play satellite bus, the SpaceDev, Inc. Trailblazer spacecraft bus, and the Air Force Office of Scientific Research (AFOSR)/AFRL NanoSat-4, CUSat.

The Trailblazer spacecraft was ultimately selected by the ORS Office approximately six weeks prior to launch. In addition to the ORS primary payload, Flight 3 also carried a RideShare Adapter experiment for a SpaceX commercial customer, as well as two CubeSat payloads.

SpaceX gained experience in the late manifesting of payloads, rapidly executing coupled loads analyses and executing the various procedural and contractual aspects of a launch that are not fully defined until late in the launch campaign timeline. Specifically, documentation and analysis were completed in advance so that regardless of which payload was ultimately chosen, the final integration and verification activities could be kept to a bare minimum and fit within the final two to four weeks of the launch campaign. Coupled loads analyses, collision avoidance maneuver analyses, performance and trajectory analyses, and safety analyses were completed for multiple payload configurations. Three separate interface control documents were worked between SpaceX, the team for the primary payload being considered, and the secondary payload system teams. Additionally, although unnecessary for ORS missions, the Federal Aviation Administration (FAA) demonstrated responsiveness by licensing the launch regardless of payload

SpaceX has deliberately designed its launch vehicle systems so that launch site operations are simple, quick, and efficient.

selected; FAA personnel reviewed the payload safety information from all three candidates for acceptance before granting a commercial launch license that enveloped them all.

SpaceX had previously demonstrated a responsive launch operations campaign in March 2007 on the Falcon 1 second demonstration mission for the Defense Advanced Research Projects Agency with support from the US Air Force. The US Air Force "clocked" operations and determined that SpaceX could launch the Falcon 1 within 77 hours after hardware arrived at the launch site. Although this span was not a contiguous 77 hours since multiple shifts of launch operations personnel were not working around the clock, the measurement indicates that a rapid launch campaign is achievable to meet the ORS objective of a six-day call-up to launch.

Figure 5. SpaceX Falcon 1 integration processing at Omelek Island launch site.

Launch site operations are greatly simplified with SpaceX's use of horizontal processing of the launch vehicles. All work is performed at "man level," precluding the need for any vertical service structure at the launch pad.

Upon arrival at the launch site, each of the two launch vehicle stages undergoes a receiving inspection and a simple health check prior to being integrated together. Once fully integrated, the vehicle is run through a complete hardware in the loop test in order to verify the functionality of both the avionics software and the critical hardware actuation mechanisms.

Integration of the spacecraft to the fairing and payload adapter cone is done vertically. After encapsulation, the fairing assembly is rotated horizontally and attached to the vehicle in the hangar. Following attachment, the fully-assembled vehicle is lifted onto a transportation dolly for movement to the launch pad. As shown in figure 5, this operation is performed with simple "A-frame" cranes for Falcon 1/1e (rather than large capacity overhead cranes) due to the fact that the fully integrated vehicle is relatively lightweight when unfueled.

SpaceX is continuing its efforts to demonstrate its ability to meet the requirements for ORS operations. In 2010, SpaceX will be conducting a study for the ORS Office to assess the modifications necessary in vehicle hardware and software, support equipment, facilities, and processes for the Falcon 1e to meet the six-day call-up to launch objective. The launch vehicles shall be capable of being in ready storage for a minimum of one year prior to call-up. During the study, SpaceX will evaluate a number of enhancements to achieve the objective, such as onboard metric tracking, autonomous flight termination systems, and more automated mission planning to facilitate rapid retargeting of the mission trajectory.

Conclusion

US commercial launch vehicles can meet the performance and schedule requirements for operational responsive launch—and do so reliably and affordably—satisfying warfighter needs, US space policy, and Congressional direction. Highly reliable, low-cost space transportation is the singular goal that drives SpaceX. Design simplicity and hardware commonality across SpaceX's family of Falcon launch vehicles result in substantial improvements in system reliability and affordability. Falcon 1 launch campaigns have demonstrated that much progress has been made towards the objective ORS goal of 6-days from call-up to launch and on-orbit operational capability. SpaceX looks forward to continuing to work with the ORS community and it stakeholders to make this goal a reality for our warfighters.

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Prior to joining SpaceX, Mr. Bender was with ATK where he served as corporate director of business development for national security and commercial space systems in Washington DC, and division director of business development for ATK Tactical Systems in Rocket Center, West Virginia.

Prior to ATK, Mr. Bender worked for Orbital Sciences Corporation in Chandler, Arizona and AlliedSignal Aerospace in Phoenix in various business development, engineering, and financial positions.

Industry Perspective

Operationally Responsive Space:
A Spaceport Perspective

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The capability to rapidly deploy assets into space is a critical function to maintain space control for America. The current capability gap is being addressed through the Operationally Responsive Space (ORS) Office. ORS is examining the proper equipment, procedures, and personnel that must be established in the areas of satellite procurement, launch vehicle preparation, and spaceport operations. The ORS Office is heavily engaged in the most critical aspect of responsive space; creating a common bus for payload interface and establishing procedures to responsively procure satellites. At the same time, aerospace companies have created cost efficient small to medium lift launch vehicles, such as Orbital (Minotaur and Taurus class), Lockheed/ATK (Athena class) and SpaceX (Falcon class), that will be valuable for responsive use. Yet these efforts alone will not provide a truly responsive spacelift without a rapid launch spaceport. This article will address the facilities, procedures, and personnel that a spaceport requires to deliver the responsive space capability.

Monday, 0300 GMT. An undetected piece of orbital debris collides with communications satellite IS-605, knocking out a significant portion of Ku-band communications over Japan.

A rapid launch spaceport will have the facilities, procedures, and trained personnel in a ready state for extended periods of time in order to launch on short notice without the high costs traditionally associated with reserving launch facilities and keeping a large workforce on standby. The facilities must include on-site storage of the launch vehicle (LV), a LV transporter, and instrumentation configurable in hours. Procedures will be established to reduce the normal 60 to 90 day prelaunch activities into a week or less while maintaining an equivalent level of safety. Finally, these procedures must be rehearsed and validated using a trained and professional work force that is small, versatile and available for rapid launch missions. Each component of a rapid launch spaceport will be described below.

Monday, 0530 GMT. An 8.2 magnitude earthquake strikes the coast of Japan causing massive damage. Cell phones, radio, and most communication networks are damaged or overwhelmed. The government of Japan requests assistance from the US.

The foremost asset required of a rapid launch spaceport is a rocket that is ready for launch. A facility that is designed to store fully assembled launch vehicles will provide this essential capability. The launch vehicle motors and components will arrive at the spaceport processing facility well in advance of their projected use, where time can be taken to properly assemble the LV and perform all the quality assurance checks. Once the LV is assembled, a strongback transporter will move the assembled LV into an environmentally controlled storage facility, such as an earth-covered magazine. This facility will have a raised rail system that is compatible with the strongback transporter to facilitate a smooth and safe transfer to the storage bunker without any motor lifting. Once in the storage bunker the vehicle will be connected to remote monitors to provide Air Force Space Command (AFSPC) health and status information to ensure readiness of the LV. When the LV is needed, the strongback transporter carries the LV the short distance to the pad for erection. The strongback will preferably be a transporter/erector design (T/E), which has self-contained hydraulics that can rotate the LV onto the pad. The Minotaur I LV has an existing T/E, and Martinez and Turek Inc. has a design for a Minotaur IV compatible T/E. Less robust T/E designs can be used for liquid fueled LVs since the weight of the propellant is not added until after erection. A bridge crane at the pad can provide the

Figure 1. Kodiak Launch Complex.

final position adjustment for a proper mating on the stool, if needed. The pad itself will be prioritized for rapid launch missions in order to ensure its availability.

Monday, 1000 GMT. Spaceport Liberty receives notification from AFSPC to prepare a rocket for emergency launch of a communications payload to assist the Japanese. All employees on standby are recalled.

Spaceport instrumentation will be reconfigured on short notice to support the unscheduled rapid launch mission. Instrumentation provides vehicle health and status data, position information, and flight safety services. Upon receipt of a rapid launch mission from AFSPC, the instrumentation section will load stored configuration files for the specific LV allowing communication with the LV telemetry stream. Once the configuration files have been loaded and verified, and the LV erected on the pad, the operators will perform signal strength and end-to-end quality checks with the LV. Telemetry and range communications will be relayed directly between the spaceport and the Joint Space Operations Center (JSpOC) via fiber optic lines to eliminate the need for a deployed launch control team.

Tuesday, 1000 GMT. Spaceport Liberty moves a fully assembled rocket from the storage facility to the launch stool. The telemetry systems operators load the LV specific configuration files and begin system tests and calibration.

With prior indications that a rapid launch may be necessary, the satellite can be pre-shipped to the spaceport and stored in the payload processing facility. Payload and bus integration and transportation to the spaceport is the pacing item for rapid launch, therefore having an assembled satellite on site is an ideal situation that will greatly reduce the time required for launch. For emergency scenarios, the satellite will likely be new construction from the Rapid Response Space Works or a ready spare out of storage. In the absence of a ready spacecraft stored at the launch range, the satellite will be in transit to the spaceport while the LV is being prepared. As soon as the satellite arrives, it will be checked out, fueled, encapsulated, and mated to the LV for end-to-end system tests in preparation for launch. This process, as well as the other LV and range preparation tasks, requires procedures to allow the concurrent work of many disciplines at the spaceport.

Wednesday, 1200 GMT. ORS communications satellite (SATCOM)-2 arrives by air from the Rapid Response Space Works satellite storage along with a technical team. The satellite is taken to the payload processing facility for final checkouts, fueling, and fairing installation. Meanwhile, AFSPC provides flight data for the launch.

Streamlined procedures will be developed, rehearsed, and tested for efficient launch processing time without compromising safety or mission objectives. Prior planning and preparation are essential to set the conditions for several dedicated mission teams to work concurrently against a rapid launch master schedule. These teams include the following:

- Mission flight planning team
- Satellite team
- Launch vehicle team
- Telemetry and flight safety team
- Ground safety team

With each team working concurrently and directly supervised by the mission manager, launch will occur in as little as five days after notification. This will be possible with extensive pre-mission preparations.

A five-day launch cycle demands detailed planning and preparation, to include payload, bus, and LV integration and is beyond the scope of this article. As previously mentioned, the LV will be processed, assembled, checked, stored, and monitored on site. Then the flight data packets for the LV will be prepared, accounting for the most likely flight scenarios and payloads. Software tools will be required to allow the flight data packets to be modified and validated in a short period of time in the event that a pre-package flight plan needs minor adjustments based on the real world situation. The launch pad will be configured for rapid launch, which includes the LV launch stool, transporter connections, environmental controls, and all necessary tools and equipment pre-positioned and accounted. The transporter must be maintained and ready to move the LV from storage. Finally, the critical communication links will be established and periodically tested and verified. These actions will assure a ready status, without requiring a large amount of resources or personnel, thereby keeping costs down.

The rapid launch mission order will be prepared at AFSPC through a military decision making process (MDMP). The mission order will identify the payload, LV, spaceport, and launch windows. Upon receipt of the rapid launch mission, each of the functional area teams will begin executing their procedures while continuously updating the mission manager of their status to maintain unity of effort. Some top-level team tasks are as follows:

- Mission flight planning team (at JSpOC)
  - Flight data packet prepared
  - Flight data packet transmitted to range, if stored scenario is inadequate
  - Coordinate downrange and other space assets to support the launch with telemetry and control
  - Prepare for launch control operations
- Satellite team
  - Perform payload tests, validate configuration
  - Accompany satellite to spaceport
  - Fuel and encapsulate satellite
  - Mount satellite on LV (with LV team) and perform final system checkout
- LV team
  - Remove LV from storage and transport to pad
  - Erect LV onto pad

- Mount satellite (with satellite team)
- Validate mission data load
- Conduct radio frequency (RF) and umbilical communication checks

• Telemetry and flight safety team
  - Upload instrumentation system configuration
  - Run telemetry and safety system tests, closed and open loop
  - Test communications with LV

• Ground safety team
  - Coordinate with law enforcement and US Coast Guard to clear maritime traffic from hazard areas
  - Conduct Federal Aviation Administration and North American Aerospace Defense Command notification to clear airspace
  - Tightly control RF emissions on range
  - Control traffic flow and maintain positive accountability of all personnel on range

By clearly defining each team's responsibilities and how they communicate, the pre-launch processing can be accomplished in a safe and orderly manner within a few days. Unforeseen challenges will present themselves in such a compressed timeline, which is why trained personnel and good leadership are the keys to a rapid launch success.

Thursday, 0500 GMT. ORS SATCOM-2 integration onto the LV is complete. LV flight data is loaded and verified. Range safety and telemetry system have completed communication checks with the LV. AFSPC provides final authorization for launch.

An important aspect of conducting rapid launch is effective leadership and a trained and professional workforce that have fully rehearsed rapid launch protocol. US ranges have a professional work force experienced with current certifications and qualifications. To add rapid launch to the workforce's repertoire, a culture of innovation must be established that actively implements methods of doing common launch activities quicker, better, and more efficiently. This workforce will likely be a small team of about 50 experienced personnel who are technically and operationally proficient across a range of disciplines. By keeping the rapid launch workforce small, it will serve as a versatile and agile group able to quickly respond to the demands of rapid launch while maintaining unity of effort. Best practices of industry will still be maintained, especially configuration management. However, shifting to a leader-driven process that uses experienced and technically proficient leaders who are empowered to be responsive, responsible, and accountable will reduce timelines. Activities that traditionally take days, such as configuration change boards, will be accomplished just as professionally in hours with proactive leadership. Such a small, motivated workforce can combine proven procedures with new technology to achieve the efficiencies needed for rapid launch.

A rapid launch protocol may look good on paper, but it must be demonstrated by live fire exercises before it can be considered a proven capability. The first step on the road to a live fire is a leadership rehearsal, where the key personnel walk through the facilities and examine the equipment needed for rapid launch. This allows the division chiefs and managers to gain situational understanding of each operational component and how it fits into the master timeline. Next is a dry run for all range and mission personnel, which is the "crawl" phase of the "crawl-walk-run" methodology. In a dry run everyone goes through their assigned tasks and procedures to work out the problems before touching hardware. The dry run is followed by a full pathfinder operation, the "walk" phase, which will validate the procedures using hardware and most of the software. Once the pathfinder is successfully completed, it will be followed by three live fire exercises; the "run" phase and the most realistic exercise possible. These live fires can use motors designated for aging and surveillance launches, and they may carry experimental or university payloads for added utility. The first exercise will budget enough extra time to ensure safe testing of new procedures. After conducting full after action review of the first live fire, adjustments will be made to reduce the timeline of a second launch. The process will repeat itself for the third launch, which will demonstrate actual rapid launch timelines.

Thursday, 0600 GMT. Liftoff of ORS SATCOM-2 to provide interim telecommunication services to the rescue and recovery efforts in Japan.

Facilities, procedures, and a workforce designed for rapid launch will result in a proven rapid launch capability, however the resulting orbit is key to a successful mission. Essential to responsive space is the selection of an orbit that will quickly provide the required coverage that the mission demands. Two types of orbits that provide significant advantages for responsive space mission design are the Tundra and Molniya orbits.

Molniya and Tundra orbits are two highly elliptical orbits (HEO) with extremely useful characteristics, specifically long dwell times over selected fixed geographic locations and the ability to "self-clean" or deorbit the satellite at the end of its life to reduce space debris. Russia first used the highly elliptical orbit called the Molniya (Russian for "lightning") because

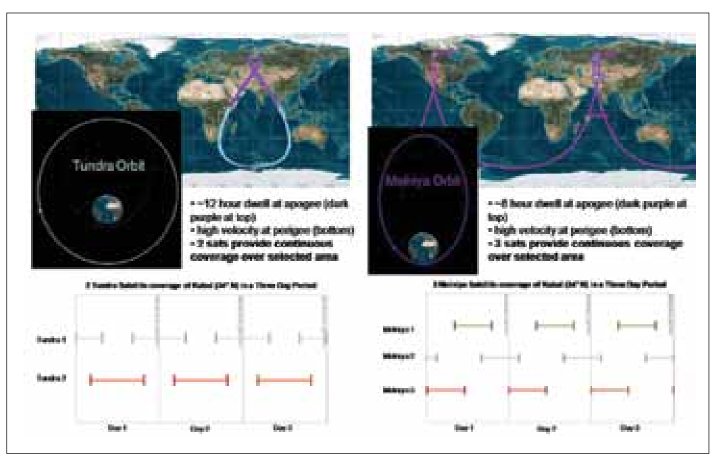


Figure 2. Tundra and Molniya performance.

it provides a long dwell time in mid to high latitudes without using a geostationary (GEO) orbit. A Molniya orbit has a period of half a day, which places the apogee over two locations on the Earth each for about eight hours a day. Molniya orbits are inclined at 63.4 degrees. This inclination is called the critical or "frozen" inclination because the extra gravity pull caused by the Earth's bulge at the equator is balanced on both sides of the orbit. Therefore satellites at this critical inclination do not experience the effect called the "rotation of perigee" caused by the oblateness of the Earth. The significance is that the ground track of the satellite will not experience the drift that other elliptical orbits experience and the Molniya satellite will reach its apogee over the same two spots of the Earth each day.

The Tundra orbit is an adaptation of the Molniya orbit, first used by Sirius Satellite Radio to provide continuous satellite coverage to North America. Like the Molniya, the Tundra orbit is inclined at the critical angle of 63.4 degrees, but the Tundra orbit has a period equal to one sidereal day. Therefore a Tundra satellite has an apogee dwell of about 16 hours over the same spot every day. The ground track is unusual because it follows a figure "8" pattern on a two-dimensional map. This allows the orbit to remain over a specific area and provide long dwell times.

The key advantage these orbits provide is the ability to target an area the size of North America, anywhere in the world, for long-term coverage day after day. There are many other benefits of these HEO orbits, including:

- Provide long dwell times over specified areas (Tundra ~16 hours for one location, Molniya; ~8 hours for two locations at opposite sides of the Earth).
- Provide high elevation angle coverage for all latitudes (~30° at the equator, overhead at mid and high latitudes, and ~60° or higher at the poles).
- Orbits are not as crowded as low Earth orbits (LEO) and GEO, less chance of space collision and radio frequency interference.
- Orbits are less regulated by the International Telecommunications Union than GEO.
- Can be easily deorbited at end of lifecycle.
- Require less fuel to reach orbit than a GEO.
- Provide asset protection by being difficult to intercept (Tundra, high altitude; Molniya, fast, both with variable altitudes).

As with other orbits, the Tundra and Molniya have their disadvantages, such as:

- Require multiple satellites to provide continuous coverage (two for Tundra, three for Molniya).
- High altitude above targeted area (similar to GEO altitude).
- May require tracking antennas for ground stations (depends on frequency and use).
- Molniya passes through Van Allen radiation belts four times a day (Tundra orbits are outside the Van Allen belts).

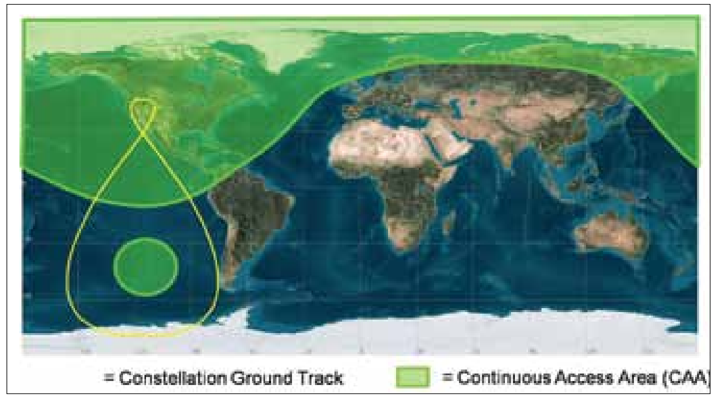


Figure 3. Tundra coverage area.

Although multiple satellites for continuous coverage may be a disadvantage when compared to a single GEO satellite, it can also be an advantage. Multiple satellites can provide layered coverage, and the loss of a single satellite (by a launch failure, for instance) will only reduce the coverage provided, instead of losing the entire capability as with the failed launch of a single GEO satellite.

Tundra and Molniya orbits provide responsive orbits, and their intermediate orbit can be used by in-orbit satellites to respond to a crisis within hours. The key is to place contingency satellites into a circular LEO in the same 63.4 degrees orbital plane as the Tundra and Molniya satellites, with a solid rocket motor (e.g., ATK Star 48) still attached to provide the eventual thrust to achieve the final HEO orbit. The satellites can remain in this intermediate orbit for years until they are needed to respond to a crisis. When the decision is made to commit the satellites and the longitude for apogee dwell is identified, the solid rocket stage will thrust the satellite directly into the required apogee with on board thrusters providing the final adjustments. In this manner, a single satellite or a constellation can provide service over a large area within a day after the crisis.

Thursday, 1000 GMT. ORS SATCOM-2 is directly inserted into a Tundra orbit over Japan where it joins ORS SATCOM-1, recently boosted into a Tundra orbit from its parking orbit. Together they provide 24/7 communication services throughout the region three days after the request for assistance from the devastating earthquake.

There are four operational US civil spaceports with a record of performing orbital launches that can be configured to provide rapid launch. These spaceports are:

Spaceport	Region	Location
Kodiak Launch Complex (KLC)	West Coast	Kodiak Island
Spaceport Systems International	West Coast	Vandenberg AFB
Space Florida	East Coast	Cape Canaveral
Mid-Atlantic Regional Spaceport	East Coast	Wallops Flight Facility

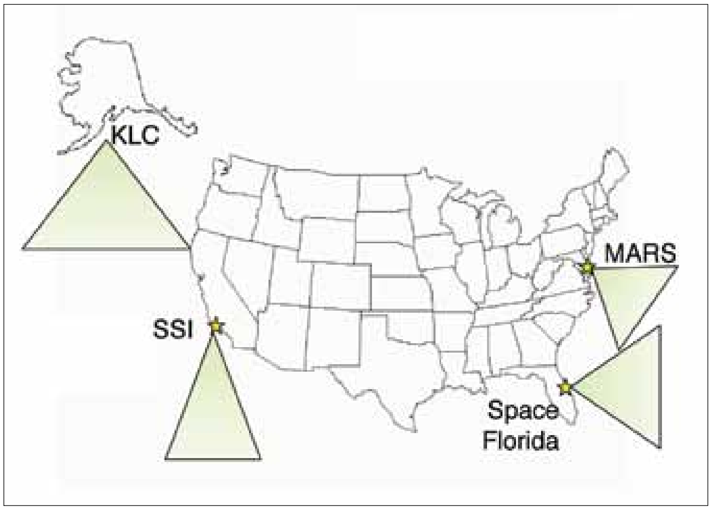


Figure 4. Spaceports.

Each spaceport offers small and medium spacelift for a variety of orbits. At these spaceports, small and medium spacelift missions are the primary effort, with responsive launch schedules and existing instrumentation for tracking, telemetry, and safety. The launch azimuth and inclination diversity from these spaceports will provide AFSPC the flexibility to choose the spaceport that best supports the mission parameters. The general location and launch azimuth for each range is depicted in figure 4.

As ORS requirements evolve, Alaska Aerospace is continuing to improve infrastructure, procedures, and workforce management to mature the Kodiak Launch Complex (KLC) as a responsive launch spaceport. A centerpiece to this effort is the construction of the Rocket Motor Storage Facility (RMSF) that will consist of five earth covered magazines, with each magazine capable of storing a complete launch vehicle configured for rapid launch. Horizontal rail transfer systems in each magazine will allow motor transfer between the magazine and transporters without a crane lift. When the first two earth-covered magazines are complete in 2010, the RMSF will allow a LV to be taken from storage and be placed on the pad in about an hour. Using all five magazines, up to five LVs can be launched within a week. KLC already has an advanced Rage Safety and Telemetry System configurable within an hour to provide flight termination and telemetry data products for a number of LVs. Furthermore, the primary launch pad at KLC is fully enclosed by a climate-controlled tower with a 75 ton bridge crane. This launch pad is already configured to interface with the existing Minotaur I transporter/erector. These facilities and equipment, combined with the highly skilled labor force, is the first step to establish a true strategic rapid launch capability. Alaska Aerospace Corporation is working with AFSPC, ORS, and other responsive launch spaceports to ensure facility compatibility with responsive satellites and launch vehicles. With rapid launch spaceports, the US will be able to break the space-access paradigm and maintain America's supremacy in the high frontier.

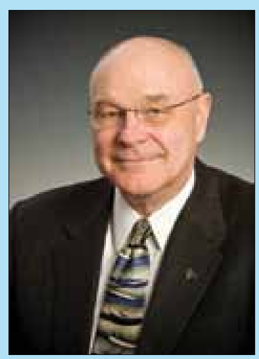
Mr. Dale K. Nash (BS, Engineering, University of Utah; MBA, University of Florida) is the chief executive officer of the Alaska Aerospace Corporation (AAC). Dale joined AAC as the chief operating officer in January 2007 and was promoted to chief executive officer in February 2008. Alaska Aerospace is a state owned independent corporation that owns and operates the Kodiak Launch Complex (KLC). To date 14 successful launches have been completed out of KLC with two Air Force Minotaur IV launches scheduled later this year.

Mr. Nash has 28 years experience in the aerospace industry with 14 years on National Aeronautics and Space Administration's Space Shuttle/Human Space Flight programs and 11 years on Department of Defense ballistic missile systems and solid rocket motors.

Mr. Nash began his aerospace career in 1982 at Hercules Aerospace Company - Bacchus Works Magna, Utah working on intercontinental ballistic missile and submarine-launched ballistic missile systems (SICBM). He moved to Thiokol Corporation - Promontory, Utah in 1987, where he was promoted to director, Materiel for the Strategic Missile Division working on the Trident I and II, MX, SICBM, and Castor 120 programs.

Thiokol transferred Mr. Nash in 1993 to Kennedy Space Center (KSC) as the vice president/general manager for Thiokol's Florida operations including processing and stacking Thiokol's Solid Rocket Motors and Lockheed's External Tank. As the Space Shuttle Program consolidated into a single operations contractor beginning in October 1995, Dale transitioned from Thiokol to Lockheed Martin to United Space Alliance (USA).

At USA Mr. Nash served in several executive leadership positions including program manager supporting the Lockheed Orion team, director launch operations at KSC, director ground systems at KSC and director external tank/solid rocket booster operations.



Lt Gen Thomas R. Case, USAF, retired (BS, US Air Force Academy; MS, Systems Management, University of Southern California; National War College and US Army Command and General Staff College) is the president and chief operating officer of the Alaska Aerospace Corporation (AAC).

General Case has 33 years experience in US Air Force and joint duty assignments. After concluding his active duty US Air Force service, General Case was the University of Alaska Anchorage's dean of the College of Business and public policy for five years prior to joining AAC as president and chief operating officer in April 2008

Highlights of his military career include a combat tour in Vietnam as a forward air controller followed by operational flying assignments in the F-4, F-16, and F-15E. He served two tours of duty in the Pentagon, first as a tactical weapons requirements officer, and then as the Air Force director of modeling, simulation and analysis. He commanded a fighter squadron in Germany, the 51st Wing in Korea and the 3d Wing at Elmendorf AFB, Alaska. He served for two years as the US Air Force chief of staff's chair on the faculty of the National War College.

As commander of Alaska Command, Alaska NORAD Region and 11th Air Force, he gained experience as a user of space-based systems. Combatant command experience included his serving as the J-3 operations officer for US Central Command (USCENTCOM) and then deputy commander USCENTCOM. He also served as deputy commander for US Pacific Command.

Benefits of Returning to the Original Vision of Operationally Responsive Space

Mr. John Roth
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Sierra Nevada Space Systems
Louisville, Colorado

Years after the development of the initial concept of operationally responsive space (ORS), it is still a concept that is not clearly understood by many, and therefore the debate about the merits and true warfighting utility of ORS continues. This article provides some historical information on the original intent of the ORS model and highlights the potential game-changing benefits if the original vision for ORS is followed.

The Roots of ORS

One of the early sources of planning guidance that led to the ORS concept was the fiscal year (FY) 2003-2007 Defense Planning Guidance dated August 2001. In Part II, Strategy Guidance, it states, "The president has directed DoD [Department of Defense] to achieve progress in transforming the US defense posture to meet the security challenges of the 21st century. The aims of transformation are to maintain a substantial margin of advantage over potential adversaries in key functional areas of military competition (e.g., information warfare, power projection, space, and intelligence) and mitigate the effects of surprise."[1] Shortly after this report was released, former Secretary of Defense Donald Rumsfeld created a new Office of Force Transformation (OFT) reporting directly to him and appointed Vice Admiral Arthur Cebrowski, USN, retired as the director. Admiral Cebrowski is generally credited with development of the ORS concept and was a passionate advocate for development of small, low-cost "tactical satellites" that could be rapidly developed and launched where they would be directly tasked by theater warfighters to provide direct dissemination of intelligence information into theaters of operation.

As conceived by Admiral Cebrowski, ORS was a term used to describe a new *business model* which would be complementary to the traditional space acquisition model of developing "systems designed and paced for large national security capabilities."[2] He compared the ORS business model to Harvard Business School Professor Clayton Christensen's Disruptive Innovation Model, in that it targeted lower performance in "traditional" attributes, but improved performance in new areas; and targeted customers who historically lacked access to its product. Key to realizing the ORS business model is the use of smaller satellites (under 1,000 kilogram [kg] and down to micro and nano-satellites) which are developed much more rapidly and at lower cost. These small satellites have short cycle times with high-speed iterative advancement in capabilities between successive satellites, and a focus on demand-driven capabilities for operational and tactical-level support as shown in figure 1. Attributes of these small satellites include a focus on single-missions rather than encompassing requirements for multiple missions, sub-optimized but effective payloads (i.e., "good enough" performance for tactical needs), and far shorter life spans that serve both to keep the development costs low and allow rapid technology refresh in space through spiral development and launch of incrementally improved spacecraft.

The advantages Admiral Cebrowski saw for such a model were numerous, including:

- Reduced burden on national space systems and the organizations that operate them.
- Enhanced persistence of national systems.
- Enabled adaptability of US forces to changing information needs.
- Reduced vulnerability of the space network through larger quantities of systems and the ability to rapidly replenish capabilities.
- Provided a test bed for larger national military space systems.
- Enhanced the professional development of military and industry space talent by greatly expanding the opportunities to work on satellite development and mission operations programs.

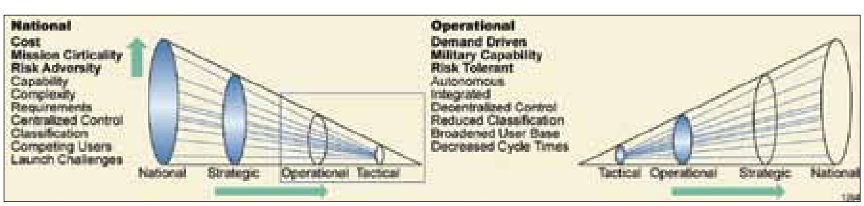

Figure 1. A key attribute of ORS is that field commanders drive the demand for products based on capability needed to meet operational and tactical level needs. Source: Admiral Cebrowski Testimony to Senate Armed Services Committee.

As conceived by Admiral Cebrowski, ORS was a term used to describe a new business model which would be complementary to the traditional space acquisition model of developing "systems designed and paced for large national security capabilities."

In March 2004, Admiral Cebrowski described his vision for ORS to the Senate Armed Services Committee's Subcommittee on Strategic Forces.[3] He received strong support from Congress resulting in substantial increases to the OFT budget to continue development of the ORS concept and experimentation with tactical satellites. Congressional support, both from members and professional staff, eventually led to the National Defense Authorization Act for FY 2007 requiring the DoD to develop a "Plan for ORS" and to establish an office to manage ORS activities. This plan was developed by DoD and submitted to Congress in April 2007 establishing the current ORS Office which is headquartered at Kirtland AFB, New Mexico.[4]

ORS Satellite Progress to Date

In May 2003, the Office of Force Transformation initiated a program for ORS satellite experimentation with a focus on tactical satellite (TacSat) applications.[5] The idea was to demonstrate the essential elements of responsive space, such as rapidly developed, capable, small satellites, low-cost development and launch, theater payload tasking and data dissemination, and use of commercial networking tools such as internet protocol routing via the Secret Internet Protocol Router Network. Initially, the mission and payload selected was not of primary importance, what mattered was a physical substantiation and demonstration of the elements of ORS satellites. The overall goal was "to demonstrate the utility of a broader complementary business model and provide a catalyst for energizing DoD and industry in the operational space area."[6] The Naval Research Laboratory (NRL) resonated with the OFT Office vision and agreed to work in concert with OFT in development of the first tactical satellite dubbed TacSat-1.

My involvement with the OFT Office began soon after the TacSat-1 program was initiated. In 2002, I had taken the position of president of a small satellite developer, MicroSat Systems Inc. Our primary customer had been the Air Force Research Laboratory (AFRL) Space Vehicles Directorate. Nearly all small satellite efforts at the time were limited to research and development activities and technology demonstrations at Universities or in military laboratories like NRL and AFRL. We had been fortunate to be selected as the prime contractor on a program called Technology Satellite for the 21st Century (TechSat-21) which was focused on demonstrating operational utility of small satellites. TechSat-21 was an ambitious program to develop a constellation of three small satellites with synthetic aperture radar (SAR) payloads that could fly in close formation and demonstrate coherent ground target imaging between the distributed SAR payloads. As president of a small, high performance satellite developer, I was naturally drawn to the OFT vision of small, capable satellites built on shorter timelines and targeted at tactical support to warfighters rather than merely technology experiments. I initiated contact with the OFT Office and had the privilege of working with Admiral Cebrowski and other visionaries within OFT until Admiral Cebrowski's death in 2005.

One of the important original tenets of ORS was the rapid, iterative advancement of capabilities that was to be realized by a continuous process of spiral development and deployment of satellites. The OFT vision was to initiate TacSat demonstrations as often as every year in a spiral development process to rapidly realize improvements in satellite bus and payload capabilities in the same way that commercial industries, such as personal computers, benefit from having six-month to one-year life spans for a given capability level. This evolutionary approach is possible because of the faster development time, lower cost, and shorter planned mission life of the ORS satellites. The traditional military space model of five to 10 plus year development cycles followed by 15-year mission life requires more revolutionary changes be incorporated since opportunities for new generations of satellites are many years apart. This need to push state of the art capabilities into new developments increases development risk and cost and has led to often cited overruns in cost and schedule on large space programs.

As a good example, the TacSat-1 and TacSat-2 satellites were planned to be developed on overlapping schedules, with TacSat-2 launching within a year of TacSat-1. TacSat-2 was executed by AFRL in conjunction with OFT and MicroSat Systems was selected to provide the satellite. Both satellites were to carry versions of the NRL target indicator experiment (TIE) payload. The TacSat-2 TIE payload was to be an evolutionary improved version of the TacSat-1 TIE payload, benefiting from lessons learned during TacSat-1 development and early on-orbit employment. Although TacSat-1 did not launch due

Figure 2. The TacSat-2 satellite demonstrated the key attributes desired for ORS satellites.

to launch vehicle issues, TacSat-2 did carry an upgraded version of the TIE payload and was launched in December 2006, successfully performing numerous experiments and supporting multiple operational exercises over its planned one-year mission life.

Subsequent TacSat programs include TacSat-3, a hyperspectral imaging satellite developed by AFRL that was launched in May 2009 and has demonstrated impressive performance on-orbit, and TacSat-4, a communications augmentation satellite developed by NRL and planned for launch in 2010.

Where TacSat demonstrations led by the military laboratories are focused more on demonstration of technical capabilities for various small satellite missions, the ORS Office is developing ORS Satellites (ORS Sat) that focus on demonstrating real-world operational utility of lower cost, smaller satellites. The first such mission is ORS Sat-1 which will provide color pictures of regions selected by ground force commanders, and use existing ground systems to process and distribute the images and other information out to the battlefield. ORS Sat-1 is currently in development and is scheduled for launch in 2010.

Current Focus of ORS Office

As with any innovative new concept, the ORS concept has evolved over time from the original vision of Admiral Cebrowski and OFT to the current vision of the ORS Office. In the DoD report to Congress in April 2007, the structure and goals for the new ORS Office were defined in a broader sense than just rapid launch of small satellites. ORS was described in the context of three Tiers: Tier 1 (employ) which is focused on the use of existing assets, including on-orbit satellites, to address urgent needs in a matter of minutes or hours; Tier 2 (deploy) focused on establishing and utilizing a store of on-call, ready-to-field assets that can be employed in days to weeks; and Tier 3 (develop) focused on rapid transition from development to delivery of new or modified capabilities in months.[7] Figure 3 shows the desired end state for how the ORS Office will operate.

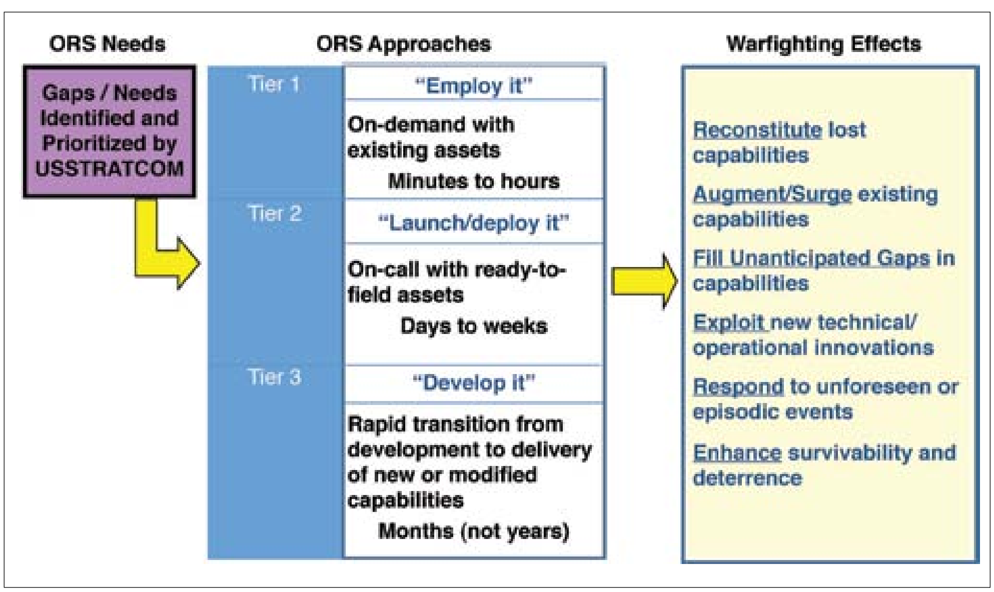

Figure 3. Desired end state: ORS joint processes meeting JFC needs.

The ORS Office has maintained a focus on the Tiered-approach to establishing these capabilities from its inception in 2007 to the current on-going procurement for the Rapid Response Space Works/Modular Space Vehicle (RRSW/MSV) contract. When fully operational, the RRSW is intended to provide the capability for the ORS Office to use small satellite technology to meet rapid response times for commander, US Strategic Command-defined time-critical operational needs. This is to address the Tier 2 concept of establishing and utilizing a store of on-call, ready-to-field assets. The MSV tasks are focused on development of a multi-mission, modular bus and modular payload concept and hardware to support future ORS Sat missions. The modular architectures are to incorporate standards developed both by the NRL-led Integrated Systems Engineering Team which was formed in support of the TacSat-4 program to define general ORS-class satellite standards, and the AFRL-led spacecraft plug and play avionics standards. The result of the MSV program will be modular buses and payloads that can satisfy future Tier 2/3 needs.

Are We Missing Important Benefits from the Original ORS Vision?

Although the current ORS Office efforts include many of the features of ORS envisioned by the Office of Force Transformation in the early inception of the ORS business model, there are basic tenets of ORS that are no longer at the forefront. In some cases, I believe this is more from resource constraints than from a lack of belief in their value by the ORS leadership. One of the important original tenets of ORS was the rapid, iterative advancement of capabilities that was to be realized by a continuous process of spiral development and deployment of satellites as demonstrated on TacSat-1 and TacSat-2. After TacSat-2, this objective has not been realized. TacSat-2 launched in 2006 and demonstrated many of the key features of ORS, but TacSat-3 did not launch until two and a half years later, in May 2009, and was based on a different satellite platform and had a different payload, so no real evolutionary improvements in capability were demonstrated.

In addition, much of the work on TacSat-4 was performed concurrently with TacSat-3; however, there was little real coordination between the programs resulting in meaningful evolutionary steps. Funding constraints no doubt played a part in the slower development cycle and lack of synergy between programs, as well as an initial absence of a single guiding authority, since the TacSat satellites were being developed by different service laboratories, AFRL and NRL, before the ORS Office was established. Another constraint on rapid development has been contracting realities. Early proponents of ORS realized the need for streamlined procurement authorities to reduce the time required to initiate a new program and get to award of a contract, but to date the contracting methods have followed the traditional authorities and timelines. In fact, even though acquisition streamlining was identified early on as a critical enabler for the ORS model, the OFT Office does not currently do their own acquisitions, but uses other organizations such as the service laboratories, and even NASA, for contracting for ORS efforts.

A second key tenet of ORS that is missing today is that "quantity has a quality all its own." Although originally attributed to Joseph Stalin in reference to Russian tank production in World War II, it applies equally well to the benefits of having many satellites with a variety of payloads and flying at various orbits. Logic tells us that the more satellites in-orbit, the greater the instantaneous global coverage, persistence, and diversity in viewing angles and over-flight times. Additionally, more spacecraft means less vulnerability from attack or failures of any single satellite. One can also envision the benefits that constellations of ORS satellites could have to the overall *space architecture* in terms of augmenting national and strategic assets and filling gaps in capabilities and coverage. Small satellite constellations with a variety of payload sensors (such as electro-optic [EO], infrared [IR], hyperspectral [HSI], and synthetic aperture radar [SAR]), and in a variety of orbit altitudes and inclinations could be fielded to provide a diverse picture of the theaters of interest.

The on-going fiscal reality is that we are barely able to recapitalize existing space capabilities, let alone increase the numbers of major military satellites or add significant new satellite capabilities to the space architecture if we follow the traditional space model. Fielding significant quantities of small, far lower cost satellites can provide needed augmentation to existing capabilities.

Even in terms of the quality of the information that can be obtained from satellites, there is an advantage to be gained by a variety of assets available, even if lower resolution. As an example, although a national satellite may have exquisite image resolution that cannot be matched by an ORS-class satellite, the "mission relevant information" that might be obtainable by simultaneously gathering lower resolution EO, IR, HSI, or SAR views of the same target area, perhaps even simultaneously, could far outweigh a single exquisite image.

In addition to the in-orbit benefits of many satellites, the building and launching of many satellites provides an excellent training opportunity for military and civilian engineers in satellite assembly, integration and test; decreases infrastructure costs by amortizing required assets over many satellites; leads to decreased launch vehicle costs through increased number of launches; provides ground station operator experience in flying the satellites, tasking the payloads, and developing and disseminating the products; and provides the warfighters a continuous experience basis for utilizing the products effectively for real-world mission support.

Again, what has been achieved to date in ORS has not allowed these benefits to be realized. The ORS Office budgets the last few years have only been adequate to keep a single major focus program, ORS Sat-1, moving forward. The president's proposed $94 million budget for FY 2011 is not encouraging as it represents a reduction of more than $30 million from the $124 million OFT Office budget for FY 2010. Given the need to complete, launch and operate the ORS Sat-1 satellite, very little will be left over to fund new programs. What is disappointing to those of us that see the huge potential for a fully realized ORS vision is that this funding level is an insignificant fraction of the overall military space budget, and far less than the typical overrun on a single large satellite program.

Coupled with the lack of adequate funding for the OFT Office to develop and demonstrate operational utility of the ORS satellites is the non-existence of funding in the services current and future budget lines to procure ORS satellites in reasonable number. Since each ORS satellite is more limited in capability than large, much higher cost satellites, the utility is in fielding them in constellations rather than one at a time. While the ORS Office has the lead in demonstrating operationally capable satellites, they do not have the charter or budget to then build many copies of the satellites, launch them and operate them. The concept is for the services to budget for the recurring satellite costs and operational employment, but to date there has been little noticeable progress toward that end.

Conclusion

Originally conceived as a new *business model* rather than a specific set of missions, ORS has game-changing potential for military utility if employed as originally envisioned by Admiral Cebrowski. Some good first steps have been taken in the

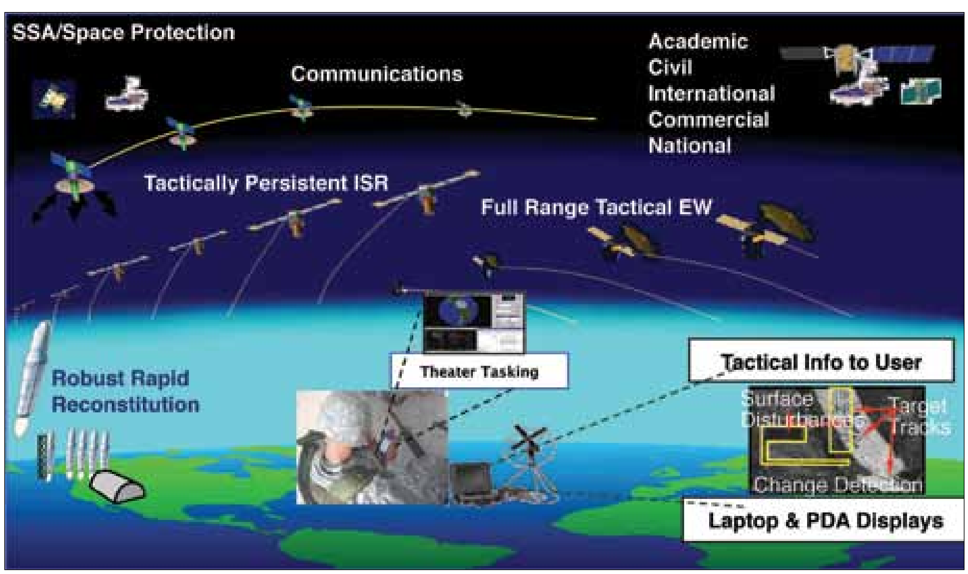

Figure 4. The ORS model of low cost, multi-mission satellites supports a layered architecture approach that adds depth, persistence, and vulnerability to the existing space architecture.

eight years since the effort was started in the OSD Office of Force Transformation, and then migrated to the ORS Office in 2007, but the pace of development has been too slow relative to the achievable benefits to warfighters. Until DoD provides adequate funding to the ORS Office to allow them to increase the pace of development and the services budget adequately for building and launching ORS constellations and plan the capabilities into the future space architecture, the true value of ORS will not be realized.

Notes:

[1] Final Mission Need Statement AFSPC 001-01, Operationally Responsive Spacelift, 20 December 2001.

[2] Arthur K. Cebrowski and John W. Raymond, "Operationally Responsive Space: A New Defense Business Model," *Parameters*, US Army War College Quarterly, Summer 2005.

[3] Statement of Arthur K. Cebrowski, director of force transformation, Office of the Secretary of Defense, before the Subcommittee on Strategic Forces Armed Services Committee US Senate, 25 March 2004.

[4] Department of Defense Plan for Operationally Responsive Space, A Report to Congressional Defense Committees, 17 April 2007.

[5] Lt Col Jay Raymond, et al., "TacSat-1 and a Path to Tactical Space," paper presented, AIAA 2nd Responsive Space Conference, 2004.

[6] Ibid.

[7] Col Kevin McLaughlin, from slides presented at ORS industry day, 21 February 2008.

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Toward a New Strategy for ORS

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To consider proposing a new strategy for operationally responsive space (ORS), one must know what ORS is. In Hamlet's words, "ay, there's the rub," as the term evokes a diversity of views both among those responsible for providing space capabilities to the warfighters and among the warfighters themselves. Thus, as a relatively new space concept with an intriguing name, ORS has been recommended as the way to address a host of challenges facing space.

It is well known that warfighters use a wide variety of space assets to support military operations. Moreover, if warfighters were asked if they would like more space capability, the answer would be a resounding "yes." Should ORS be the means for providing the "more," perhaps during a conflict when it is most needed (i.e., wartime augmentation)? In addition to providing more capacity, additional space assets could offer other benefits: shorter revisit times; theater tasking and data downlink; data, products, and services that are releasable to coalition partners; and support to new operational concepts, such as distributed ground operations. If the conflict is such that space is also a contested environment, should ORS be the means to rapidly deploy critical space capability to replace selected losses (i.e., wartime reconstitution)?

Even during peacetime, satellites can experience early on-orbit failure or suffer damage from orbital debris or space weather effects. Also, acquisition programs for follow-on systems can experience significant schedule slips, which could give rise to gaps in capability if the mission life of the legacy systems cannot be extended. Should ORS be the means to address these concerns (i.e., peacetime augmentation)? Given the lengthy time it currently takes to acquire most space systems, it can be difficult to provide the latest space technology to warfighters. Should ORS be the means to promote technology insertion in space acquisition? One could argue that Congress and senior Department of Defense (DoD) and Air Force leaders are unhappy with the large cost overruns and significant schedule slips of many of the nation's larger space acquisition programs. Should ORS be the means for developing a new space acquisition strategy for the DoD to ensure satellites are acquired on schedule and within budget? Some have even suggested that one way to address the acquisition problem is to acquire simpler and cheaper satellites. Should ORS be the means to promote development of small satellites and launch vehicles?

The DoD definition of ORS, "assured space power focused on timely satisfaction of joint force commanders' needs," does not appear to add much clarity; it is so general to be almost a logical tautology or truism. Replace "space" with "air" and then ask the air community what the phrase means to them (of course, the land community may likely have a different interpretation).

Although many views of the term "ORS" persist, US Strategic Command (USSTRATCOM), the combatant command responsible for DoD space operations, has focused ORS activities on two important issues of high current interest: (1) DoD's ability to rapidly augment existing space capabilities and reconstitute critical space capabilities and (2) DoD's ability to rapidly acquire new or modified space capabilities.

Further, USSTRATCOM has defined a three-tier approach to meet the joint force commanders' urgent space needs (figure 1). ORS Tier 1 provides responsive space effects within hours, through the employment of existing, fielded space capabilities. ORS Tier 2 uses ORS assets held in reserve and rapidly deploys them within days to weeks. ORS Tier 3 involves rapid development and deployment of a new capability within months to one year. The DoD currently does not have the ability to provide either Tier 2 or Tier 3 solutions within the stated timelines; if arranged before a conflict, selected Tier 1 capabilities (e.g., allied or commercial space assets) could be made available today. Implementing each tier much more rapidly than allowed by the traditional process creates significant challenges for ORS. Moreover, each tier faces a different set of challenges because each will provide a different solution set to the urgent need.

ORS Needs	ORS Approaches	
Gaps/needs identified and prioritized by USSTRATCOM	Tier 1	"Employ it" On-demand, with existing assets (immediate to hours)
	Tier 2	"Launch it/deploy it" On-demand, with ready-to-field assets (days to weeks)
	Tier 3	"Develop it" Rapid transition from development to delivery of new or modified capabilities (months to one year)

Figure 1. Operationally Responsive Space Tiers.

Recently, we were asked by the Air Force to (1) assess the feasibility of DoD's approach to ORS and (2) provide recommendations for an overall ORS strategy. We examined the responsiveness of traditional space, surveyed government and industry views on ORS, and evaluated enabling technologies to assess the risks and challenges in implementing ORS tiers (in terms of responsiveness and technical performance). Here, we briefly summarize the recent progress in ORS, describe key challenges in implementing each ORS tier, recommend ways to overcome the challenges and deliver the ORS capability in the near term, and end with our views on a new strategy for ORS.

Progress in ORS

We assert that ORS has had a positive overall influence on National Security Space (NSS) (defined as the combined space activities of the DoD and the intelligence community [IC]) and has value to DoD. First, ORS has invoked innovative ways and ideas to shorten the time to deliver space capability to orbit. In particular, the ORS Office's broad agency announcements have induced industry to respond to very challenging problems by proposing technology, process improvements, and other approaches to reduce the timeline to orbit. Second, the concept of ORS has encouraged more dialogue within the larger space community (e.g., the science and technology community, requirements and acquisition organizations, and organizations that operate space systems). For example, the execution process for ORS urgent needs involved the collaboration of subject matter experts from this larger space community to derive conceptual solutions for each urgent need. As a result, the second ORS urgent need generated about 60 conceptual solutions, including novel ways to use existing systems (Tier 1) and development of a new system (Tier 3). Third, the ORS Office outreach program has given users a better understanding of how space, and specifically ORS, could support them. Continuing education of the users is required as they often do not understand the current concept of "ORS" and its associated tiers. For them, "operationally responsive" should be a modifier of all space capabilities provided to them. Finally, various organizations have established initiatives to make space more responsive to the warfighter (e.g., Air Force Space Command's [AFSPC] ORS Capability Team, Space and Missile Defense Command's Army Responsive Space Initiative, and ORS-focused teams within space companies).

Since the ORS Office was established, it has focused its efforts on meeting warfighters' needs and has made considerable progress. The ORS Office has responded to three space urgent needs from joint force commanders (JFC) and has begun acquisition of the ORS-1 satellite in response to the third urgent need. It is testing and evaluating promising capabilities using such experiments as the TacSat series, the RADARSAT-2 demonstration, and Jumpstart. It is also addressing policy and procedural challenges in achieving rapid delivery of space capabilities, such as improving responsiveness in range, frequency allocation, encryption, contracting, and so forth.

Despite the efforts and improvements in ORS, the current approach to providing ORS capability continues to face policy, technology, industrial base, funding, and institutional challenges. Each tier is addressed in turn below.

Tier 1 Challenges

Tier 1 solutions use existing on-orbit systems to deliver the capability needed by JFCs by either employing the existing capability as is or by modifying the capability or its processes. The solution set includes using allied and commercial systems in addition to NSS systems. Current policy on international space cooperation and limited interoperability with non-NSS systems could limit the effectiveness of Tier 1.

Lagging Policy

We recognize that international systems could offer a range of Tier 1 options, as many allies and friendly countries are developing capable, smaller systems, especially in imagery collection and satellite communications. Many foreign nations have developed sub-meter electro-optic systems and capable synthetic aperture radar systems that are used for national security purposes. However, the US currently does not regularly use allied space assets broadly. Policy on international cooperation is not fully mature and it has lagged the advances in foreign countries' space capabilities. There is also an ongoing debate regarding the potential risks associated with reliance or dependence on foreign systems for wartime operations. Yet, agreements need to be in place with international partners as well as with commercial partners in advance of a contingency.

Limited Interoperability

Implementation issues in leveraging a non-NSS system could very easily make a Tier 1 solution ineffective. The DoD does not regularly use most allied and commercial systems (except for satellite communications), and there is limited commonality between these and the NSS systems. Foreign and commercial systems have their own processes, data formats, tools, and systems for tasking and data dissemination, as the ground and user segments of a satellite tend to be system-specific, with limited standardization across systems. For direct access to the Tier 1 system and data, interoperability of tasking and dissemination systems and compatibility of data formats are needed. Direct access is desirable to minimize data latency and to maintain some level of discreteness if the US is involved in a conflict.

Concerns about information assurance could also limit the use of non-NSS Tier 1 systems. Non-NSS systems may have different information assurance standards that may not be compatible or acceptable. Validation of the networks, tools, systems, and processes to ensure integrity of the data or service could be a lengthy, difficult process, which needs to be worked out well in advance of a contingency.

Limited Training Opportunity

Currently, opportunities and mechanisms to exercise the end-to-end process for non-NSS systems are limited. As a result, users will not be familiar with the capabilities of the system; the tasking, collection, processing, exploitation, and dissemination (TCPED) concept of operations (CONOPS); the tactics, techniques, and procedures (TTP); and the tools to rapidly employ non-NSS Tier 1 systems on demand.

The recent Joint Reconnaissance Platform (JRP) experiment highlighted some of the potential challenges in employing an ORS Tier 1 asset. In this experiment, operational control of a US space capability was delegated to a combatant command. The purpose of the experiment was to test the theater-tasking concept and to assess the utility of the capability for the operational-level warfighter. However, fully operationalizing JRP took significant time. Theater collection managers were not familiar with the system, and thus there was a heavy reliance on reachback to subject matter experts for system knowledge and data exploitation. It is crucial to exercise the capabilities of Tier 1 systems and the end-to-end TCPED process if capabilities are not being used routinely during peacetime, so that users are operationally ready in times of crises.

Recommendation: NSS Should Take the Lead on Tier 1 and Include Allied and Commercial Systems

Traditional space should take the lead on delivering the Tier 1 capability by continuing to improve responsiveness of its existing architecture and by including allied and commercial systems.

Operational elements of the NSS community would argue that they are continually examining ways to make their systems more responsive, especially for the warfighter, as part of their normal operations (e.g., by modifying ground segment processes or operating satellites differently). Further, other efforts address longer-term Tier 1-like initiatives, such as the services' tactical exploitation of national capabilities (TENCAP) programs. Nevertheless, the NSS community should continue to find ways to make current and future systems more responsive to warfighters. For instance, it may be worthwhile to examine the end-to-end process for current systems to ensure that they are as responsive as possible. The shortfall may be in the TPED portion of the TCPED process rather than in collection. Some warfighters believe that much can be done with respect to products and dissemination, such as Google Earth using national imagery. Also, future US systems should be designed with increased flexibility. For example, space systems could be designed with net-centric operations in mind for enhanced data-sharing. Finally, by integrating allied and commercial capabilities into the NSS architecture, many of the implementation issues are addressed as part of the operations of NSS. Policy, CONOPS, TTP, and interoperability can be refined and matured within the context of NSS, ensuring that Tier 1 systems can be employed rapidly. This approach also enables routine use of allied and commercial systems to maintain user proficiency and readiness levels.

ORS Tier 1 has been, and should continue to be, the responsibility of the NSS community. DoD and the IC should continue to improve the responsiveness of the existing NSS architecture for the warfighter, and they should negotiate agreements with allied nations and commercial providers in advance to ensure that DoD has access to their space capabilities on short notice.

Tier 2 Challenges

To enable the Tier 2 capability, the ORS Office is focused on developing enablers, including prototypes, for the rapid deployment of small, low-cost space systems within days to weeks. However, organizational, fiscal, technical, and market uncertainties question the feasibility of implementing Tier 2 in the near term.

Requirements and Funding

The lack of validated requirements for Tier 2 capability could lead to funding risks for the services, which are responsible for acquiring and operating Tier 2 systems. The need for Tier 2 capability has not yet been validated and hence the CONOPS and requirements (technical capability and deployment timeline) for Tier 2 systems are not well defined. Neither USSTRATCOM's 2009 ORS CONOPS nor its 2008 ORS Strategic Command Instruction addresses the CONOPS for Tier 2. As a result, there is uncertainty about whether the proposed short-deployment timeline is necessary, especially as timelines could be highly scenario-dependent. Therefore, the launch rate, surge capability, and the capability or missions that need to be reconstituted or augmented, including the number of systems, are also not well defined.

Moreover, answers to these currently ill-defined parameters will likely vary significantly, depending on whether one is concerned with wartime reconstitution, wartime augmentation, or peacetime augmentation (none of which is obviously a subset of the other). Note that wartime augmentation could also be required for a "disadvantaged" theater (i.e., one not involved in a major conflict), as it may have limited access to traditional NSS systems that are now being provided to another theater with higher priority.

Without the need validation and top-level requirements, the funding for Tier 2 systems will be difficult to obtain, constraining the services' ability to acquire ORS satellites. Further, laboratories and industry need specifications and a set of guidelines to develop technologies and systems.

This lack of well-defined mission needs, CONOPS, and requirements leaves room for a range of interpretations that could lead to development of a solution that is incompatible with the real need. The mission need and CONOPS drive the requirements and solution space for space vehicle, launch vehicle, and ground segments, which then drive the technology solutions. However, the current path to Tier 2 solutions is mostly a technology push. The technologies and enablers are driving the solution space for Tier 2. Further, without the requirements, it will be difficult to measure how well any solution meets the users' needs.

A joint and interagency team, led by AFSPC, has begun the needs validation process by conducting a capabilities-based assessment (CBA) for USSTRATCOM and the ORS Office. The CBA team calls this capability rapidly deployable space (RDS).[1] This term also has more clarity for users than the more ambiguous "ORS." The initial capabilities document, resulting from the RDS CBA, will be forwarded to the Joint Requirements Oversight Council for approval. In addition, an analysis of alternatives may be required to assess a range of solutions, including airborne and terrestrial assets, that could meet the various mission needs.

Logistical and Cost Risks

Although technical requirements for Tier 2 systems are still uncertain, there is a general consensus that existing small satellite technologies would be suitable for Tier 2 solutions. Technology for small satellites is sufficiently mature; capable small satellites are emerging and are used for a wide range of applications, especially in the international community.

The current Tier 2 hurdles are mostly due to the short deployment timeline goal (days to weeks). Even for small satellites, the satellite build cycle (1-3 years), launch vehicle build cycle (12-18 months), range safety and operations (up to 18 months for Eastern and Western Ranges), launch site operations (30 days), and on-orbit checkout (weeks) all require a lengthy timeline. Some critical satellite components can take months to over a year to obtain.

As a result, the ORS Office is focused on technology development that is associated with rapidly delivering an on-orbit capability (rapid assembly, integration, and tests [AI&T], launch, and early on-orbit checkout). The ORS Office is also addressing many of the long-lead processes (e.g., range safety, frequency allocations, and encryption) by exploring options such as obtaining pre-approvals with advance planning.[2] To tackle the launch vehicle build timeline, the ORS Office is proposing that an inventory of fully built launch vehicles be placed in storage, awaiting payloads. For the satellite build, the proposed approach is to maintain a robust inventory of components, payloads, and buses to overcome the long-lead parts issue and to use standards (e.g., standard mechanical and electrical interfaces), modularity (e.g., modular payloads and modular, multifunction buses), and open architectures (e.g., plug and play architecture) for rapid AI&T and mission customization.[2]

Cost uncertainty associated with establishment of depot organization and facilities could be significant and might lead to cost risks for the services that acquire Tier 2 systems. The modular components and common parts would reduce the inventory cost compared to maintaining a stock of all the necessary parts for a wide range of satellite designs. However, costs associated with personnel, floorspace, and equipment for operating the depot for both the satellites and launch vehicles could easily outweigh the inventory cost and could be significant. First, AI&T and launch personnel in a stand-by mode are necessary to rapidly respond to a need for build and launch of a Tier 2 satellite. A wide range of testing equipment and facilities may be necessary, depending on the testing requirement for Tier 2 systems. Additional personnel and resources are required for storage and inventory management. Storage facilities must be adequate to maintain the desired storage life of the components, as certain components may require environmentally controlled facilities (e.g., clean rooms) and special storage facilities (e.g., for batteries or propellants). Inventory management requires periodic assessment and update of inventory content and level, such as checking and testing of components and re-stocking components as necessary (e.g., to account for storage life, consumption, or for technology refresh).

Most of all, cost risk arises from the uncertainty in many variables that dictate the depot requirement. Frequency of launch, number of satellites and launch vehicles to be launched, testing standards and requirements, and the level of modularity of satellite components determine the required depot capacity and use of the depot (i.e., how often is the depot producing and launching Tier 2 satellites). As discussed above, these variables have not been well defined, which creates a large uncertainty about the cost-effectiveness of the depot approach.

The store and launch-on-demand approach could lead to infrequent launches and could place users at a disadvantage because it provides limited opportunities to train and exercise. Even if the capability can be placed on-orbit within days, if the users need time to learn how to use the system effectively, the Tier 2 solution may not be delivered within the timeline goal. Similar to the non-NSS Tier 1 systems, employing Tier 2 systems requires testing of CONOPS and other ground support elements to ensure operational readiness in times of crises. Although the ORS Office plans to build Tier 2 prototypes that would test the CONOPS and utility of Tier 2 systems, more frequent launches of Tier 2 systems may be necessary to support regular exercises and other training opportunities to maintain proficiency and readiness levels.

Technology Risks and Limited Market Support

The success of rapid AI&T critically depends on the maturity of the Tier 2 enabling technologies discussed above. They are currently at a relatively low maturity level and the ORS Office is working to mature these technologies by 2015. However, unstable funding for these technologies raises concerns about their availability and maturity in the near term. The ORS Office's budget was initially established at about $100 million per year. The director of the ORS Office allocates the budget between enabler development and acquisition of a Tier 3 system if a JFC need arises. ORS is anticipating that by 2015, the cost of satellite and launch would be less than $60 million with the Tier 2 enablers in place. Meanwhile, the cost of delivering a Tier 3 solution is likely to be much higher than $60 million. For instance, the first Tier 3 system, the ORS-1 satellite, is estimated to cost over $200 million for the whole mission.[3] Acquisition of a Tier 3 system could use up the entire ORS budget and significantly delay the maturity of these technologies.

In addition to maturing the technologies, industry needs to be on-board with the proposed standards and architectures. However, it is highly uncertain whether wide market acceptance of these standards and architectures could be achieved. There is initial industry reluctance because the business case is not clear (we found this view to be held by smaller companies as well as large prime contractors). Adopting new standards and architectures requires that industry (satellite manufacturers and suppliers) make some initial capital investment, such as in new tooling and equipment, even though the return on the investment is uncertain because of what still appears to be a low-volume satellite market. Industry is concerned that the ORS market may never attain a sufficient volume to support standardization and plug-and-play technology. Further, satellite manufacturers are concerned about sustaining a competitive edge. Bus manufacturers have their own "standards" (e.g., standard buses and avionics modules) and other streamlining approaches (using modular designs and common parts) that are often proprietary, which allows them to be competitive.

Many bus standards and interface standards have been developed, but they have not achieved wide acceptance across the space industry. In 2008, the Integrated Systems Engineering Team (ISET) completed development of bus standards that could be used to support a range of ORS missions.[4,5] Industry members were key participants in the development. However, the progress in maturing these standards and gaining industry support has been stagnant. The ISET business case team reported that a block buy would be necessary to realize any standardization and production benefits.

Recommendation: NSS Should Include Smaller Systems and Frequently Launch Them On Schedule

As yet, there has been no stated compelling need to have a short deployment timeline for a broad set of mission needs. One could argue that wartime reconstitution could require short deployment timelines, especially in a contested space environment, but that the timelines for wartime augmentation and certainly for peacetime augmentation could be much longer.

Given the many risks in the current approach to Tier 2, alternative approaches should be considered to ensure delivery of ORS capability in the near term. We propose that NSS incorporate Tier 2 systems (i.e., smaller satellites) into its architecture and launch them frequently on schedule. In effect, the launch-on-demand of Tier 2 is eliminated and Tier 1 capability is expanded. Incorporating Tier 2 systems into NSS improves the robustness of NSS by diversifying the available capability and providing redundancy. Further, the funding source for Tier 2 systems is clarified. Trades required to enable funding for Tier 2 systems would be conducted within the context of NSS, as Tier 2 systems are part of the solution set for NSS missions.

Frequent launch-on-schedule mitigates much of the risk associated with the short deployment timeline. First, it is a relatively low-risk approach that could deliver the ORS capability in the near term. Much of the technical risks associated with rapid AI&T can be avoided, as industry can already deliver capable smaller satellites, just not within the short deployment timeline. Second, logistical and cost challenges associated with storage can be avoided, and the latest technology would be available to users. Third, deployment risk during a contingency is reduced, as the systems are already on orbit. Fourth, frequent launches improve proficiency and readiness levels in times of need by enabling both users and ORS operational ground elements (e.g., command and control, satellite operations) to train and exercise from end to end. The users can learn the benefits and limitations of these smaller systems in a warfighting scenario. As a result, lessons learned can be used to mature ORS CONOPS and update or modify ORS requirements.

Moreover, frequent on-schedule launches increase the number of systems on orbit, which has additional benefits. Proliferation of these systems improves survivability and hence mission assurance. Increased numbers and frequency of launches can stimulate the industrial base and improve the responsiveness of the space infrastructure. Further, smaller systems could satisfy the less-demanding needs of space users during peacetime and may increase capacity for the so-called "exquisite" NSS systems to address the difficult needs for which they were designed. Hence, the use of smaller systems in NSS allows peacetime augmentation.

We recognize that launch-on-demand may be needed for a small subset of wartime reconstitution scenarios. In this case, the number and type of satellites is likely to be limited, and one can envision meeting this type of critical high-priority need, for example, with systems on quick alert (i.e., the satellite mated to the launcher and the launcher on a transporter-erector in a shelter near the launch pad). Although the launch can be accomplished quickly to meet the deployment timeline, there is no need to quickly assemble the satellite or launch vehicle, as that has been done in advance. This option deserves further exploration for feasibility and cost. We note that there are Cold War and current analogies for lessons learned.

We also note that the Tier 2 systems (i.e., smaller satellites) are in a different category of systems in terms of costs and capability. Thus, a small satellite system program office, separate from the traditional acquisition organization, may be needed to implement a different acquisition approach for Tier 2 systems.

The services are responsible for acquiring and operating ORS Tier 2 capabilities. In the near term, frequent on-schedule launches of smaller satellites are recommended to provide training opportunities as well as redundancy for on-orbit systems. This should enhance operational proficiency and readiness, as well as mission assurance and minimize the need for rapid, launch-on-demand capability. Funding for Tier 2 systems should be provided within the context of the larger NSS enterprise, as Tier 2 systems should be part of the solution set for NSS missions. However, funding as part of a larger NSS program may not be possible in the near term, and Tier 2 will face funding challenges as a new program in a budget-constrained environment.

Tier 3 Challenges

Given its stated goals, Tier 3 is really an example of acquisition reform. It faces many organizational and fiscal challenges, but the ORS Office's unique organizational attributes and the more limited scope of Tier 3 capability may enable rapid acquisition.

Enabling Attributes for Rapid Space Acquisition

A Tier 3 solution requires development of a new or modified capability within months to one year, with a cost goal of less than $60 million for the space vehicle and launch vehicle. Tier 3 is essentially tackling the space acquisition problem, as the US cannot acquire space systems quickly at low cost. The root causes of long acquisition timelines for space systems have been attributed to many factors, such as a long and complex requirements process, requirements creep, funding instability, multiple stakeholders, underestimation of technology readiness, and an inexperienced workforce, among others.[6] AFSPC leaders are very aware of the problems with space acquisition and are making a determined effort to restore credibility to the space acquisition process. These efforts are discussed in the command's *High Frontier* magazine, which devoted its November 2009 edition to the topic of space acquisition.

The current approach to Tier 3 and some of the unique attributes of the ORS Office may avoid many of the root causes leading to lengthy acquisitions. First, the requirements process for Tier 3 acquisition is shortened significantly. Tier 3 systems do not go through the DoD's Joint Capabilities Integration and Development System process. If the urgent needs process is followed, the requirements for Tier 3 should be well defined and validated before the start of an acquisition. The requirements are need-specific for a single user (a JFC) and a single mission, thus minimizing their complexity. Second, the ORS Office is taking a risk-tolerant approach, rather than a risk-averse approach, to streamline the acquisition process. The focus of a Tier 3 acquisition is schedule, cost, and then performance. As a result, Tier 3 solutions are limited to smaller systems that are less complex and that do not require long mission life or significant technology development. Finally, the ORS Office reports directly to the DoD Executive Agent for Space. This direct reporting line enables the ORS Office to obtain some waivers and deviations, and it eliminates the long chain of command that could slow down an acquisition process. Having a minimal number of key stakeholders should also temper the potential for requirements creep.

Implementing the Tier 3 acquisition approach will not be without challenges. The approach is not designed to fit into the traditional space construct. It is a break from accepted government space acquisition standards, practices, and expectations, and thus coordinating ORS with the established space acquisition community could be challenging. Also, achieving acceptance by the broader space community that a risk-tolerant approach for operational space systems, even for Tier 3, is appropriate could be a major hurdle. Further, delivery of a Tier 3 system depends on the maturity of the enabling technologies. As mentioned above, funding stability for enablers is an issue with the current ORS budget. The ORS Office is currently working through these challenges with the acquisition of the ORS-1 satellite.

Recommendation: The ORS Office Should Focus on Rapid Acquisition of Low-Cost Space Systems

Rapid acquisition is an important capability that needs to be developed to meet ORS needs. No US organization currently exists to provide rapid space acquisition. Thus, creation of a new office offers an opportunity to exercise innovative acquisition models, rather than attempting to condense and adjust those of the main-stream space acquisition community. Lessons learned from other acquisition models (e.g., the Secretary of the Air Force's Rapid Capability Office, Big Safari) could be assessed and incorporated as appropriate. Acquisition of the ORS-1 satellite and other future systems could be pathfinders for rapid acquisition, and lessons learned can be transitioned to the larger space community. The ORS Office could evolve into the DoD's Rapid Space Capability Office (RSCO), or, in time, a service could step up to that challenge. The RSCO can use the small satellite system program office discussed above or another acquisition organization as the executing agent.

To effectively use its limited resources and unique attributes, the ORS Office should focus on delivering the Tier 3 capability and enablers. Furthermore, the ORS Office should obtain the necessary authorities and staffing to be an effective acquisition agency. To ensure funding stability for Tier 3 and the enablers, the DoD should require that Tier 3 systems be accompanied by sufficient funding from the requesting stakeholders and users. The current ORS Office budget should be dedicated to technology and enabler development.

The ORS Office should focus on delivering ORS Tier 3 solutions and responsive space technology enablers to demonstrate and establish a needed US government capability, namely, rapid space acquisition. Renaming the office the Rapid Space Capability Office would underline that focus.

A New Strategy for ORS

ORS has had a positive influence on NSS and has value to DoD. However, implementing the ORS tiers poses many challenges and whether the ORS capability would be available in the near term is uncertain. As a result, we recommend a new strategy for ORS. The NSS community should continue to address many of the issues now under the ORS umbrella to expand its continuing effort to improve its robustness and responsiveness. Tier 1 and Tier 2 systems should be incorporated into NSS. That is, NSS should be diversified with allied and commercial systems and smaller satellites that are in the "good enough" category, along with the exquisite, advanced systems. Frequent on-schedule launches of smaller satellites are recommended to provide training opportunities and to increase redundancy, which can improve the survivability of current NSS systems. Further, frequent on-schedule launches can minimize the need for launch-on-demand Tier 2 capability. The ORS Office should focus on providing Tier 3 solutions and responsive space technology enablers to ensure the success of rapid acquisition. Tier 3 rapid acquisition is not designed to fit into the traditional space construct and the ORS Office could be a valuable pathfinder to rapid space acquisition. The robustness of NSS could be improved with this new strategy to provide responsive space capability to the warfighter in the near term.

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Notes:

[1] Lt Col Ryan Pendleton, AFSPC, "Rapidly Deployable Space Capabilities Based Assessment: Approach and Status," paper presented at the AIAA 7th Responsive Space Conference, Los Angeles, California, 27-30 April 2009.

[2] Thomas Adang and James Gee, "Creating An Agile, All-Space Architecture," *Crosslink* 10, no. 1 (Summer 2009): 6-11.

[3] John T. Bennett, "ORS Program Faces 'Go/No Go Review' on July 15," *Defense News*, 14 July 2009.

[4] D. Brenizer et al., "A Standard Satellite Bus for National Security Space Missions: Phase I Analysis in Support of OSD/OFT Joint Warfighting Space Satellite Standards Efforts" (Lexington, MA: MIT Lincoln Laboratory, March 2005).

[5] Integrated Systems Engineering Team, "ORS Bus Standards Transition Plan," Phase III Deliverable, ORSBS-005 and NCST-D-SB030 (Washington, DC: Director for Defense Research and Engineering, 6 November 2007).

[6] Defense Science Board/Air Force Scientific Advisory Board Joint Task Force, "Acquisition of National Security Space Programs" (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, May 2003). (Informally referred to as the Young Report.)

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Mr. Gary McLeod (BS, Physics, University of Minnesota; MS, Astronomy, California Institute of Technology) is a senior policy analyst and project leader in the Technology and Applied Sciences department at the RAND Corporation. Mr. McLeod has over 20 years experience analyzing a wide range of command and control; intelligence, surveillance, and reconnaissance; interoperability; and space issues for the US Air Force, US Pacific Command, the Office of the Secretary of Defense, the Joint Staff, and the intelligence community. Recently, Mr. McLeod has focused his research on a number of challenges facing National Security Space. He is currently co-leading a study sponsored by Air Force Space Command that is examining the ground infrastructure for operationally responsive space (ORS). Prior to this, he led Air Staff-sponsored studies on leveraging allied space systems, developing a new strategy for ORS, enhancing joint command and control of space forces, and preparing for DoD's new dynamically taskable space systems. Mr. McLeod has also participated in two studies that examined the challenges facing space acquisition and another that sought to improve air and space integration.

Operationally Responsive Space from a Launch Vehicle Perspective

Mr. Mark Pieczynski
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Total systems solutions, rather than one-off development programs, are required to meet the growing need for operationally responsive space (ORS) capabilities. The focus should be on the design, production, and operation of integrated expendable launch vehicle and payload solutions which have the capability to be deployed on a "call-up" basis in a short duration to rapidly supplement, surge, replenish, and reconstitute operational assets on orbit. The Taurus II launch vehicle currently being developed by Orbital Sciences Corporation could be an integral element in a comprehensive end-to-end US Air Force industry based ORS strategy due to its inherently straightforward configurable design, simplified propulsion, and minimal ground-based infrastructure.

ORS is typically characterized as the ability to rapidly respond to USG space launch needs within a limited timeframe. This encompasses all activities necessary to successfully deliver high priority, security sensitive payloads to orbit.

Traditionally, ORS activities have primarily focused on the development of specialized launch vehicles and systems specifically designed for rapid deployment and launch. The "vision" for ORS has long been unique, typically reusable or partially reusable launch vehicles which embrace principles of rapid call-up and launch. These basic precepts include any time call-up, short (if any) payload analytical integration, rapid spacecraft and vehicle processing, quick deployment and launch, and, in the case of reusable launch vehicles, aircraft-like operations for quick turnaround and redeployment. These are admirable goals. While these concepts have been successfully applied to unmanned arial vehicles of various configurations and applications, and launch vehicle based missile defense systems, their successful implementation in new payload delivery to orbit launch systems has to date been limited at best.

Figure 1. Minotaur launch vehicle.

That said, there are specific examples of the adaptation of ORS principles to traditional launch systems. The Delta II Global Positioning System (GPS) launch program successfully orbited 48 GPS spacecraft over the course of 20 years, and is unquestionably the US Air Force's most successful launch program to date. The GPS program adapted to reflect ORS principles through a successful strategy of inventory management, standardized requirements, dedicated launch team, and expedient launch. The GPS program demonstrated the ability to successfully launch within 60 days of call-up, a milestone which has not been matched by any other orbital launch system. Certain design and procedural changes were implemented over the course of the GPS program to enhance the operational responsiveness of the Delta II system. These included standardized launch vehicle to payload interfaces and environments, well-established processing and mission timelines with dedicated staff and facilities, and the ability to check-out and store launch ready or nearly launch ready vehicles. However, the ability for the GPS program to demonstrate this responsiveness was primarily due to a US Air Force acquisition and risk mitigation strategy that provided sufficient funding to continue uninterrupted launch vehicle production despite slippages and delays in GPS spacecraft production and availability. This resulted in a "launch ready" inventory of vehicles, prepared to be processed and launched at the discretion and direction of the US Air Force. Thus, operational responsiveness was demonstrated by a program that was not intentionally designed to do so.

Orbital Sciences Minotaur program has similarly demonstrated successful execution of ORS requirements. Orbital's Minotaur series of launch vehicles provides a low risk, low cost, high performance launch solution for US government (USG) sponsored missions. The ability of the Minotaur program to respond effectively to USG launch requirements has been successfully demonstrated over 16 missions. Key elements which enable the Minotaur program to reflect ORS requirements include:

- Demonstrated low risk and mature avionics and ground support equipment.
- Commonality with other Orbital programs with successful flight proven heritage.
- An active production line with demonstrated manufacturing efficiencies.
- Avionics which support GPS metric tracking, satellite-based telemetry, rapid trajectory updates, and quick integration timelines.
- An inventory of flight ready or nearly flight ready assets.

Moreover, the Minotaur program has demonstrated its ability to adapt to changing mission needs. The flexibility to change configurations as user mission requirements evolve is a key design feature of Orbital's approach with a number of final solid rocket stages and attitude control systems developed for the Minotaur IV application. This "building block" approach allows tailoring of the launch vehicle to meet specific payload needs. These features, coupled with a highly experienced integration and launch team enables the Minotaur program to respond effectively to USG ORS requirements

Both the Delta II GPS program and the Minotaur program have demonstrated that standard launch vehicles and systems can accommodate ORS requirements under the right conditions.

Ideally, however, ORS or ORS-like requirements should be considered and adopted into the design requirements for new launch vehicles and payload systems. Early adoption of such concepts as fundamental requirements of new launch systems could likely yield more expedient and fiscally responsible solutions to benefit USG programs. This includes implementation of acquisition and risk mitigation strategies that facilitate the ready availability of launch vehicles to meet USG launch needs.

Orbital Sciences Corporation is currently engaged in the development of a new launch system, Taurus II. The Taurus II vehicle and associated infrastructure is being designed initially to meet the requirements of the National Aeronautics and Space Administration Commercial Orbital Transportation System and Commercial Resupply System programs. However, Orbital Sciences is making specific efforts to consider and incorporate aspects and principles of ORS into the design of the Taurus II launch system. These include:

- Lean, modular, and efficient assembly principles for launch vehicle assembly.
- Complete system check-out and verification prior to pad roll-out.
- Rapid roll-out and launch (within 48 hours).
- Simplified liquid propulsion system with environmentally friendly propellants.
- Mobile and easily replicated ground infrastructure elements.

Orbital Sciences believes the incorporation of these and other design elements can and will facilitate the execution of ORS requirements. However, the ability of Orbital Sciences to work with the USG to implement acquisition and risk mitigation strategies similar to those successfully demonstrated on the Delta II GPS program would be integral to the ability of the Taurus II program to more fully accommodate USG program ORS requirements. An available inventory of launch ready or nearly launch ready vehicles, coupled with an efficient processing and launch capability will result in a new launch system which would accommodate most USG ORS Tier 2 desires and timelines.

Orbital Sciences looks forward to filling the emerging gap in the US medium lift market with the introduction of the Taurus II launch vehicle. We also look forward to providing the necessary on-orbit assets in support of our warfighters.

To Success!

Mr. Mark A. Pieczynski is vice president of Orbital's Sciences Southern California Engineering Center in Huntington Beach, California. In his position, Mr. Pieczynski oversees the technical support provided to Orbital's various launch vehicles and space systems programs from the company's newest facility, as well as being responsible for on-site staff management and development. In particular, Mr. Pieczynski is responsible for achieving Orbital's strategic goal of evolving the Huntington Beach engineering facility to be a center of excellence for liquid rocket propulsion. Additionally, Mr. Pieczynski is responsible for developing and executing the Company's Strategic Space Launch Roadmap and for Taurus II Business Development.

Since 1995, Mr. Pieczynski has held a series of senior-level positions on Delta launch vehicle programs for McDonnell Douglas, The Boeing Company and, most recently, United Launch Alliance (ULA) that included responsibility for engineering, manufacturing and launch site activities, as well as contractual and financial matters. From 1995 to 2002, he served as the program manager for the deployment of Iridium low-Earth orbit communications satellites aboard Delta II rockets. In 2002, he was promoted to director of US Air Force Delta II Programs, overseeing the launch of military spacecraft for the US Department of Defense and its agencies such US Air Force (global positioning system constellation deployment), National Reconnaissance Office, Defense Advanced Research Projects Agency, and Naval Research Laboratory. During that tenure, Mr. Pieczynski was responsible for the successful delivery to space of nearly 90 satellites.

For the 15 month period prior to joining the Orbital team, Mr. Pieczynski served as the Delta Program site executive in Southern California, overseeing a workforce of over 900 ULA employees. He was responsible for coordinating the transition process for the ULA employees at the Huntington Beach location while all Delta rocket programs were being moved to ULA's new Denver, Colorado location. His areas of responsibility in that process included maintaining a program knowledge base to successfully transition the programs, serving as the primary interface between Boeing and ULA, and overseeing all employee-related transition activities for those employees who chose to relocate and those who chose not to transfer to the Denver location.

Responding at the Speed of Need

Mr. William G. Hart
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Raytheon Company
El Segundo, California

The concept of responsive space—rapidly deployable satellites that meet urgent tactical needs—has rightly received much attention in the last several years. As the pace of information exchange has increased dramatically, as threats to our troops reflect a new era of asymmetric warfare, as space itself becomes a contested domain, the need for less expensive, demand-driven solutions has become critical. Responsive space promises to address that need with a concept of operations tuned to the speed of need.

The responsive space vision is one that we share wholeheartedly at Raytheon. But we are not going to get there under the same paradigm that has ruled the space industry for decades. To achieve the promise of responsive space, we—government and industry—must do things differently.

Innovation thus becomes a key driver if we are to meet the challenges of the changing global threat environment, and it is innovation that I would like to address here.

There are three key areas in which we must consider innovation: In industry, we need to employ innovation not only in the creation of new technologies, but in the way we provide those space capabilities. For government's part, there must be a renewed commitment to innovation in our acquisition and export policies. And finally, industry and government must find innovative ways to partner more effectively.

From an industry perspective, our mission is fairly straightforward: provide our government the tools it needs to support the national interest. When viewed through the lens of responsive space, that means delivering ever more cost-effective and timely solutions that meet urgent, evolving needs.

Industry and government are making great strides in this area. Entrepreneurial companies are developing a new class of launch vehicles that can significantly reduce the cost per kilogram of sending space assets into orbit. Spacecraft design, too, is changing to allow for more standardization and common plug-and-play interfaces for payload integration. The effect is to make access to space more affordable, and more routine, than ever before. It also effectively addresses the speed issue.

Responsive Space Payloads

Representative of this approach in the payload market is Raytheon's Responder™ modular space payload design. Based on a standard template, Responder is capable of accommodating a suite of interchangeable sensors to meet specific mission requirements. In other words, when we build a payload based on Responder, the basic framework is the same every time. The great innovation here is that only the sensor itself requires mission-specific customization.

The Responder designs, an electro-optical (EO) and a radio frequency (RF) version, are based on Raytheon payloads flying today. Our ARTEMIS hyperspectral imager aboard the TacSat-3 satellite served as the pathfinder for the EO Responder, while NASA's Lunar Reconnaissance Orbiter carries our Mini-RF technology that served as the basis for RF Responder.

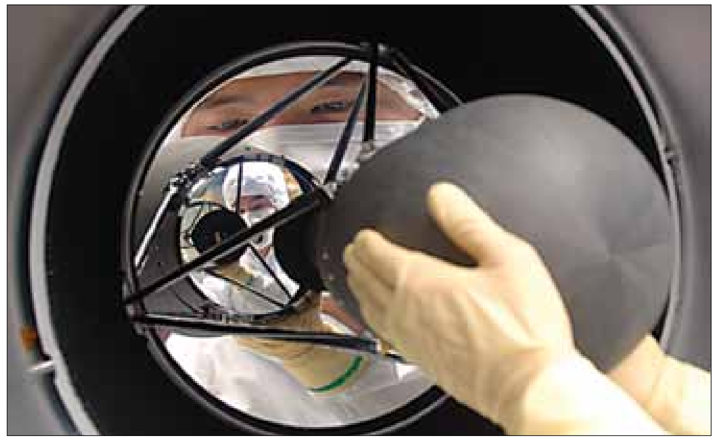

Figure 1. A Raytheon technician adjusts the ARTEMIS hyperspectral imaging sensor at the company's El Segundo, California, space manufacturing center. ARTEMIS was launched aboard TacSat-3 on 19 May 2009.

This approach to payload development holds several advantages for the warfighter. Most importantly, through standards-based, repeatable design elements, cost, schedule, and program risk can all be greatly reduced. Accordingly, rapid payload design, in tactically relevant time frames, becomes a reality. Architectures leveraging multiple space assets can be deployed for about the same cost as a single, traditional satellite.

The following are types of solutions industry can bring to the table when combining these innovations in launch vehicle, spacecraft, and payload design:

- Potential gaps in existing capabilities or constellations can be quickly and affordably filled.
- New technologies can be inserted to supplement the current space architecture and avoid on-orbit obsolescence.
- Finally, should existing space assets unexpectedly fail or otherwise become compromised, they can be more easily replaced.

I have met with a number of my counterparts on this subject, and I can tell you that there is real momentum behind creating a new paradigm in industry focused on achieving the responsive space vision. As an industry we must continue to collaborate on developing not only new technologies, but new approaches to using proven technologies for quicker, more effective results.

Industrial Base Considerations

There are some things that government can do in terms of being innovative in their approaches to industry as well. The first involves helping to stabilize the industrial base. The goal of course is that our nation maintain its technological preeminence, and that the warfighter stays one step ahead of the enemy, with products that work as they should, all the time, every time.

Most readers may be aware of the "bathtub effect," the term that describes the current aerospace workforce demographic in which there is a large gap in experience between our senior and junior engineers. Additionally, one in four aerospace engineers today is eligible for retirement. Across industry, we are working to secure knowledge transfer and maintain the integrity of our supply base. These are challenges in any industry, but it can be particularly difficult in the aerospace and defense industry because of the unique nature of the components we rely on. Let's face it, we cannot just walk into a hardware store and buy everything we need.

Improving the current procurement process will help ensure the continuity of technical expertise that runs throughout our industry. Today, we have built a process that is designed to keep bad things from happening. The reasons for that are understandable—there have been many problems with defense programs in recent years. But we must also look at the unintended consequences of such a policy. Schedules are elongated; progress is slowed. That can disenfranchise the younger engineers who are the ones we need to fill the bathtub I mentioned earlier.

I would encourage us to look at a process that is designed to make good things happen quickly, rather than one that adds steps to avoid bad things that may never happen. That will speed things up, help foster an environment of entrepreneurism, appropriate risk-taking, and innovation. Maybe—more importantly—inspire the next generation of engineers to join the defense business rather than follow other options that today seem more exciting (e.g., video games or Web design).

A responsive space-type architecture fits right into this approach. With industry focused on a steady stream of smaller satellites, we will avoid the peaks and valleys that characterize program staffing under the current procurement strategy, and we will have a built-in process for knowledge transfer through continuous, connected development work.

A More Robust Export Policy

Another way government can support US industry is through export policy reform. A more robust export policy, especially around space, will not only help stabilize the industrial base, but will also save taxpayer dollars due to economies of scale.

One approach would be to design for exportability up front. With key technologies pre-approved for export, we could open up new international markets, strengthening US foreign relations and benefiting our allies. It would also generate cost savings for the government, fueling greater investment in research and development that would in turn translate into more advanced products from industry.

This type of export strategy synchs up with the responsive space approach as well; in fact, the modular, standardized approach Raytheon has taken with Responder is transferable to international trade. It is all about taking advantage of proven (approved) technologies and processes, and eliminating non-recurring engineering.

The third area in terms of innovation is partnership. Industry and government must work together in terms of research and development to overcome emerging threats to our nation. All must be in lock step through well-coordinated communication to keep the US competitive on the battlefield.

That partnership must extend to the acquisition process, design and development, and manufacturing, as well. This close partnering is especially important on responsive space programs where requirements stability, close coordination and open communication are especially critical in meeting tight cost and schedule requirements.

If we collectively maintain our commitment to innovation, to continually seek new and better ways to do things, we will soon reap the benefits that the responsive space vision holds for our industry.

Mr. William G. "Bill" Hart (BS and MS, Electrical Engineering, Northeastern University, Boston, Massachussetts) is vice president and general manager of Space Systems for Raytheon Company's Space and Airborne Systems business. In this position, he is responsible for overseeing all Space Systems programs; developing the organization's vision, strategy and plans; and directing change management efforts.

Space Systems produces space and space-qualified solutions for defense and civil applications. Key technologies include optics, radar, laser, infrared, on-orbit checkout and calibration, and signal and data processing. Programs include the Visible Infrared Imager Radiometer Suite, the Block 06 sensor for the Space Tracking and Surveillance System, advanced missile warning technology, ARTEMIS, Responder™ and various classified efforts.

Before joining Space Systems, Mr. Hart was director of Deployable Collection programs for Raytheon Integrated Defense Systems. In this role, he led sensor business execution and growth, including major efforts such as the Ballistic Missile Defense System radar development program, and the radar's Whole Life Service and Support program. He also was responsible for the Terminal High Altitude Area Defense and SBX programs and for overseeing the operations of several fielded radar systems for the US Missile Defense Agency, working with teams deployed across the globe.

Mr. Hart joined Raytheon in 1975 as a Missile Systems Division co-op student. Throughout his career with the company, Mr. Hart has held positions of increasing responsibility in design and development; systems engineering and software development; systems test and evaluation; and production. His business management experience includes serving as president of a joint venture company and leading several technology, development, and production programs.

He is also a graduate of Raytheon's Engineering and Advanced Management programs and the Raytheon Learning Institute's Program Management and Program Leadership programs.

Observations on the Role of Dedicated Spacelift for Nanosat-Class ORS Applications

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Long Beach, California

For participants of recent small satellite conferences, small payload rideshare workshops, CubeSat workshops and other similar venues, the growing momentum for nanosat and, in particular, CubeSat-class missions is readily apparent.[1] Once primarily the realm of academic institutions, CubeSat-related projects are now underway at the Air Force Research Laboratory (AFRL), Army, National Reconnaissance Office, National Science Foundation, National Aeronautics and Space Administration (NASA), Aerospace Corporation, Boeing, and other government and commercial organizations. These represent the next steps in an overall trend by the military and intelligence, surveillance, and reconnaissance (ISR) communities towards smaller space systems.[2, 3] Their small size, launch manifesting flexibility and above all, low cost, potentially make nanosats, and CubeSats in particular, the kind of disruptive technology that has transformed personal computers (PC), cell phones, and unmanned aerial vehicles.

The discussion here attempts to briefly summarize and integrate a number of observations about the spacelift elements of missions featuring these very small satellites. The fundamental conclusion is that dedicated spacelift, based on nanosat launch vehicles (NLV) that are designed specifically for this class of very small payloads, will be needed to implement the kinds of operationally responsive space (ORS) applications now under consideration.

Background

The heritage of today's nanosats and CubeSats trace back to the beginning of the space age. The first successful US satellite—Explorer 1—had a mass of 14 kilogram (kg) (excluding the rocket section) while Vanguard 1 was a 1.47 kg sphere. The box-shaped, five kilogram OSCAR 1, developed by amateur radio enthusiasts and launched in 1961 as a secondary payload on an Air Force Thor Agena, was especially significant in that it set the precedent for manifesting such small spacecraft in this manner.

For good and for bad, it is as secondary payloads that almost all very small spacecraft have since reached orbit in the intervening five decades. A major shift occurred in 1990 with Arianespace's introduction of their Ariane Structure for Auxiliary Payloads (ASAP) on the Ariane 4. While the ASAP itself was technically significant, equally important was Arianespace's supportive attitude towards such experimental projects. Together, these factors proved to be a boon for small satellite developers, with Surrey Satellite Technology Ltd. (SSTL) becoming one of the more visible benefactors.

The trend towards offshore launch gained momentum as aerospace organizations from the former Soviet Union converted decommissioned intercontinental ballistic missiles like the SS-18 into space launch vehicles and introduced them to the global market at extremely competitive prices, essentially subsidizing the creation of a new market niche.[4] Domestically, the Space Shuttle provided unique opportunities for picosat deployment, while AFRL sponsored CSA Engineerings's development of the evolved expendable launch vehicle secondary payload adapter (ESPA) ring to leverage excess performance margins on the Delta IV and Atlas V for the Department of Defense (DoD) Space Test Program (STP).

The next inflection point came around 2000, as semiconductor and software technologies first introduced into personal computers and consumer electronics continued to diffuse into the nanosat arena. SSTL, amateur radio satellite builders, The Aerospace Corporation and others continued to validated these new capabilities through successive flight projects. In parallel, the developer community began to converge on the CubeSat standard established by Stanford and Cal Poly, San Luis Obispo. As with the original IBM PC, open standards expanded the market for suppliers and reduced the barriers to entry for new participants. Today, with as little as $25,000, it is now possible to order individual components or complete kits from suppliers like Pumpkin, Inc. and have a CubeSat lab up and running in a matter of weeks.

Missions

The diverse nature of candidate nanosat and CubeSat applications is making it a challenge for space planners to categorize them into a few discrete mission sets. However, from an NLV developer's perspective, there do appear to be several market segments forming (table 1) that have their own distinct performance and pricing characteristics.

Technology experiments and demonstrations
Scientific research
Rapid (Tier 2) asset deployment
Constellation deployment and sustainment

Table 1. Emerging market segments for dedicated nanosat and CubeSat spacelift.

To date, one-of-a-kind technology experiments and proof-of-concepts demonstrations have been the dominant class of nanosat payloads. Developers have usually also been the operators and come from academic institutions, although this is changing now as the STP receives an increasing number of CubeSat-type proposals from DoD organizations. For university-based teams, getting access to any orbit at minimum cost has been the top priority. Schedule risk and the costs of non-launch tasks and overhead are often discounted, in part because of the extensive use of student labor, tenured professors, and subsidized facilities. Direct project budgets can therefore be in the $100,000 range or lower. A minimal NLV capable of delivering on the order of 10 to 20 kg to a 250 kilometers (km) circular orbit would find existing demand from this segment to be on the order of tens of CubeSats per year. However, the emphasis on ultra low cost and competition with secondary payloads opportunities precludes making a viable business case solely on this market niche. For DoD experimenters, the ESPA ring and Minotaur secondary payload opportunities will continue to be among the leading options for reaching space.

Nanosat and CubeSat-based scientific research is a direct derivative of the pioneering technology experiments. It is now maturing into a viable segment on its own, as reflected through recent CubeSat initiatives by NASA and the National Science Foundation. The NASA Ames PharmaSat-1 (figure 1), flown aboard the Minotaur 1 that placed the ORS TacSat-3 into orbit in May 2009, is an example of a 3 unit (3U) CubeSat that required only 96 hours on-orbit to complete its primary biological experiment.[5] While these early missions share many of the traits of the preceding academic missions, schedule risk mitigation, more complete cost accounting and in some cases, orbital placement, are growing in importance. These requirements will justify somewhat higher prices, but probably still not enough to close the business case for a dedicated launcher.

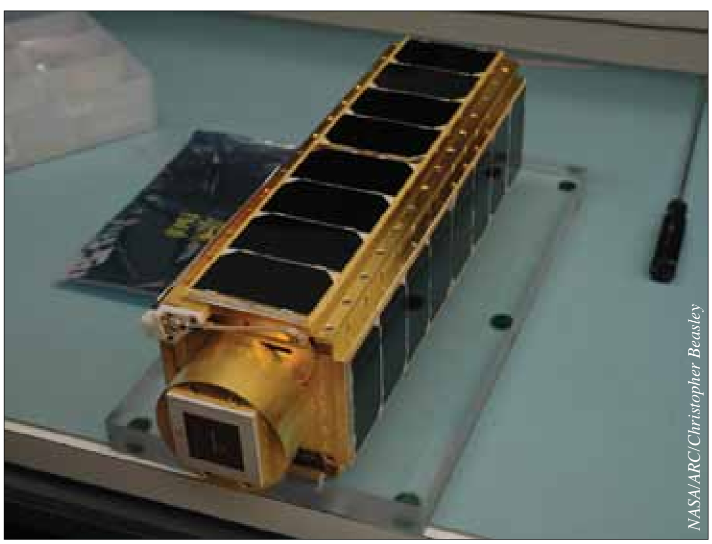


Figure 1. The NASA Ames PharmaSat 1 is typical of the emerging class of CubeSat missions for which a minimal, low-cost spacelift capability is adequate.

For prospective launch providers, it is the last two segments listed in table 1 that present the best rationale for developing a dedicated NLV. Common concepts are ISR and tactical communications applications (figure 2), for which the ability to deliver the spacecraft to specific orbits is an absolute requirement that cannot be satisfied by secondary payload positions.

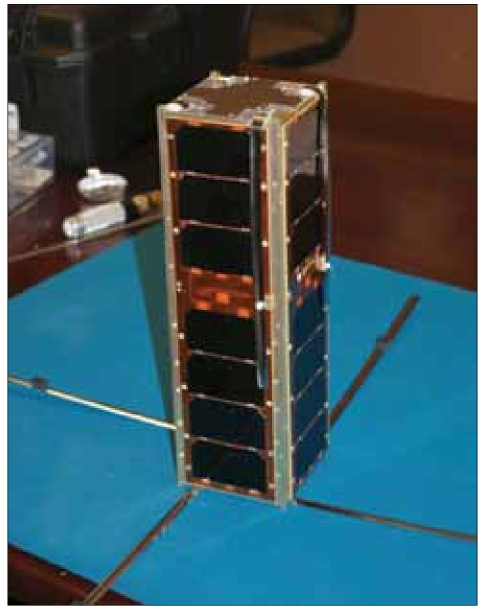


Figure 2. The deployment and sustainment of constellations of ISR and tactical communications relay satellites like the Army/Miltec SMDC-One require dedicated NLVs.[6]

Tier 2 responsiveness and schedule control follow closely as significant programmatic parameters. In many cases, the need for domestic launch and/or to control public information will also be critical.

Feedback from traditional, established operational user communities indicates that their candidate nanosat missions will require longer duration, that is higher altitude (roughly 450+ km) orbits, along with 20 plus kg payload masses. This dictates an enhanced NLV with five to ten times the performance of the minimal configuration intended for technology and science missions. Despite this greater size and complexity, with price targets in low millions of dollars per launch and the larger unit quantities associated with constellations, these segments are the ones most likely to get dedicated NLVs.

Launch

The most visible attribute of any NLVs optimized for servicing the missions identified above is that even the largest will be smaller than existing launchers. Their reduced sizes should create opportunities for reverse economies of scale in production and logistics. Inventory management is another area that could benefit. At lower unit costs, stockpiling NLVs becomes more feasible, which in turn facilitates the Tier 2 levels of responsiveness that characterized the Thor Agena space launch vehicles of the 1960s.[7, 8]

Most exciting (for launch vehicle developers at least) is that the potential for lower non-recurring expenses (NRE) enables the consideration, test, evaluation and even operational selection of multiple, independent, fully redundant launch methodologies. These can range from traditional expendable launch vehicle configurations to revolutionary concepts that attempt to fully exploit advanced technologies and architectures that have been deemed to be too risky for heritage systems.

One strategy is to first pursue expendable NLV options to achieve near-term initial operational capability at relatively low risk and NRE, while accepting higher per-flight costs. Early operations would then help to quantity demand at true cost levels while generating credibility that would in turn justify additional investments on the user side. Concurrently, enhanced research and development of reusable launch vehicles (RLV) would prepare for their subsequent introduction if/when the market demand becomes large enough to cover the additional NRE. With proper coordination, these NLVs can have traceability to and can conduct risk mitigation for the larger Reusable Booster System under investigation by the AFRL Air Vehicles Directorate.[9]

As a result of several existing launch vehicle technology initiatives, preparations for the smaller, expendable NLVs are in a relatively advanced state of development. In the case of an RLV-oriented flight test project managed by the AFRL Propulsion Directorate, flight testing of prototype NLV stages is already demonstrating Tier 1 levels of responsiveness and technology readiness levels of six for propulsion subsystem technologies (figure 3).[10] In parallel, the Army's Space and Missile Defense Command is sponsoring engine development for a multipurpose nano-missile system that could provide responsive launch services for operational systems derived from its SMDC-One and Kestrel Eye prototype nanosats.[11]

Issues

Among the many issues confronting advocates of nanosat-class missions and associated NLVs, at least four stand out. Two, the still-early state of requirements definition and the lack of true market pricing, have already been identified above. A third involves the concern that the successful deployment of large numbers of nanosats and CubeSats will aggravate the space debris problem. Such objections are based on the assumption that these will be operated like existing satellites and will be deployed in similar orbital regimes. However, an argument can be made for moving away from existing architectures. In particular, for low Earth orbit applications, a straightforward solution would be to fly these smaller spacecraft at lower orbits, such that they will not interfere with the longer duration assets above them and will come down on their own without any complicated remediation. What is usually perceived to be a net disadvantage—the shorter on-orbit lifetimes—is offset by improved image resolution, better radio link margins and more payload delivery capability for a given launcher. Furthermore, the need for constant replacement will both enable and encourage the routine insertion of technology upgrades, as will be done with the computers used in the corresponding ground control centers.

Perhaps the most difficult challenge for a proponent in this field right now is responding to a general who asks "what are they good for?" when nanosats and CubeSats are brought to his or her attention. Under such an "innovator's dilemma" situation, the usual tactic is to try to explain how these systems may enable a new mode of operations with various benefits, but that this hypothesis can only be substantiated after the fact.[12] An alternative approach might instead be to focus on the what could happen if this potentially disruptive technology is not embraced and leadership is ceded to others. SSTL is already generally recognized as the leader in small satellites. Surveys of informal lists of CubeSat projects quickly indicate that many, if not a majority, are located at non-US institutions, negating the effectiveness of technology export controls. Rides aboard Dneprs, Polar Space Launch Vehicles, and other international launchers are readily available for paying customers. It is only a matter of time before one of the emerging national space programs that are developing their own launch capabilities recognize and pursue the potential synergism with nanosats. If and when they are successful, to loosely borrow from OODA loop theory terminology, their faster cycle times will put them inside our own ability to respond.[13]

Figure 3. Ongoing flight test projects are already pathfinding Tier 2 operations and validating technologies for a first-generation nanosat launch vehicle.

Summary

Momentum for CubeSat and nanosat-class missions continues to grow as positive results from new flight demonstrations validate early applications and identify new ones. Their low cost, mass, and flexibility have the potential to transform space operations, particularly ORS, and provide a return to levels of responsiveness not seen since the early days of the space era. In parallel, technical advances continue to improve performance at the spacecraft level and are establishing the foundation for constellations of small ISR platforms and tactical communications relay nodes. While secondary launch services are critical to early test and evaluation, full exploitation will require dedicated spacelift services based on nanosat launch vehicles that are sized and designed specifically for this class of missions.

Notes:

[1] There are numerous informal definitions currently in use for categorizing very small spacecraft with masses below 50 kg. For this discussion, nanosats are considered to be those spacecraft with masses of 10's of kilograms, while picosats are on the order of kilograms, with no constraints on form or volume. Smallsats and microsats are alternative, more generic labels that can overlap both nanosats and picosats, but some users may extend their range to include 100+ kg spacecraft.

In contrast, "CubeSat" refers to the leading configuration standard for picosats and was first originated by Stanford, with California Polytechnic State University, San Luis Obispo (Cal Poly SLO) subsequently playing a major role in defining and controlling the CubeSat Design Specification (CDS). The basic "1U" CubeSat is a single 10 cm x 10 cm x 10 cm cube with a mass of 1 kg. The larger 30 cm x 10 cm x 10 cm "3U" configuration - essentially three 1U CubeSats stacked together - has grown in popularity because of its greater volume and compatibility with the Poly Picosat Deployer (P-

POD) developed by Cal Poly SLO.

[2] Amy Butler, "Reaching for the Stars, Pentagon Ambitions for large, Expensive Satellites Could be Coming to an End," *Aviation Week and Space Technology*, 30 March 2009, 45.

[3] Michael Mecham, "The Right Attitude - Major Satellite Makers Say Experience Allows Them to Compete for ORS," 30 March 2009, 48.

[4] SSTL and Cal Poly SLO have been among the leading users of such services, with Cal Poly manifesting up to 14 CubeSats at a time on a single Dnepr flight, which unfortunately failed to reach orbit.

[5] Rachel Prucey, "PharmaSat Mission Update 06.12.09," (Mountain View, CA: NASA Ames Research Center, 12 June 2009), http://www.nasa.gov/centers/ames/news/features/2009/pharmasat-update_0612.html.

[6] Bart Graham, et al., "US Army Space and Missile Defense Command Operational Nanosatellite Effect (SMDC-ONE), Program Status," presentation, CubeSat Workshop 2009.

[7] Philip Taubman, *Secret Empire: Eisenhower, the CIA, and the Hidden Story of America's Space Espionage* (New York: Simon & Schuster, 2003).

[8] T. A. Heppenheimer, *Countdown: A History of Space Flight* (New York: John Wiley & Sons, Inc., 1997).

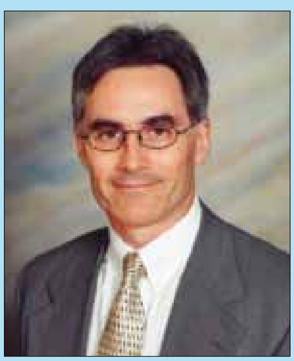
[9] AFRL Air Vehicles Directorate, "Reusable Booster Integrated Demo – Concept Options Maturation Study (RBID-COMS)," Solicitation Number: RFI-PKV-09-01, posted 11 May 2009.

[10] Garvey Spacecraft Corporation, "Demonstration and Analysis of Reusable Launch Vehicle Operations," SBIR Phase II Final Report, Report no. AFRL-RZ-TR-2009-0054 (Edwards AFB, CA: Air Force Research Laboratory / Propulsion Directorate, June 2009).

[11] Kenneth Kesner, "Company tests rocket engine that may launch affordable access to orbit for small satellites," breaking news from the *Huntsville Times* and surrounding communities, 22 December 2009, http://www.al.com/business/huntsvilletimes/index.ssf?/base/business/12614769644070.xml&coll=1.

[12] Clayton M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Boston , MA: Harvard Business School Press, 1997)

[13] Robert Coram, *Boyd - The Fighter Pilot Who Changed the Art of War* (New York: Back Bay Books / Little, Brown and Company, 2002).



Mr. John M. Garvey (AB, Economics, Harvard University; MS, Electrical Engineering, Boston University) is the founder and president of Garvey Spacecraft Corporation (GSC), a small aerospace research and development company that is focusing on the cost-effective development of advanced space technologies and launch vehicle systems. He has served as the project lead on a number of experimental launch vehicle projects, many conducted in partnership with California State University, Long Beach. Sponsoring organizations have included the Air Force Research Laboratory, Space and Missile Systems Center, the Operationally Responsive Space Office and NASA, as well as a number of aerospace prime contractors. Prior to GSC, Mr. Garvey held a variety of management positions at McDonnell Douglas and then Boeing. His launch vehicle experiences include Delta III, Delta IV, Sea Launch and the Delta Clipper-Experimental Advanced (DC-XA) vertical take-off/vertical landing prototype. He also worked on the early phases of the International Space Station and oversaw international planetary exploration technology maturation activities during the Space Exploration Initiative. He began his career at RCA Astro Electronics, where he was involved with the Shuttle closed-circuit TV and several commercial communications satellites. Mr. Garvey is a senior member of the American Institute of Aeronautics and Astronautics and has served on the Space Systems and then the Liquid Propulsion Technical Committees.

The New Space Race: China vs. the United States

The New Space Race: China vs. the United States. By Erik Seedhouse. Chichester, United Kingdom: Praxis Publishing, 2010. Figures. Tables. Panels. Abbreviations. References. Appendices. Index. Pp. xxxii, 250. $34.95 Paperback ISBN: 978-1441908797

Whether they point to the launch of the first taikonaut, Yang Liwei, riding aboard *Shenzhou-5* in October 2003, or to the anti-satellite test that destroyed *Fengyun-1C*, creating thousands of new pieces of orbital debris in January 2007, some experts see compelling evidence for an impending space race between the People's Republic of China and the United States of America. Much of that purported evidence forms the body of Erik Seedhouse's recently published *The New Space Race: China vs. the United States*. An aerospace scientist, human-spaceflight consultant, and aspiring astronaut who lives in Canada but, by his own admission, spends as much time as possible in Hawaii or "at his real home in Sandefjord, Norway," Seedhouse seems an unlikely author for this particular book. Nonetheless, he presents abundant details about past, present, and future Chinese and US civil and military space systems. He assumes that like the earlier cold war Soviet-American race, a Chinese-American competition will have both military and civil aspects.

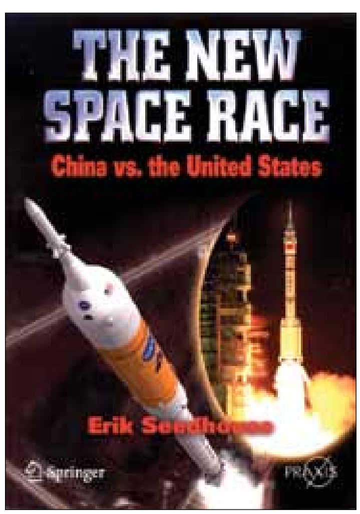
Arranging his study in four sections, Seedhouse begins with "High Frontier Politics." He discusses China's motivation for paying the financial and technological price to become only the third nation with a human spaceflight capability. "The real *why* of China's spaceflight program," he concludes, lies in the dual-use nature of space technology; beyond a variety of other nationally beneficial considerations, space systems have significant military utility. In his summary of the two nations' space policies, Seedhouse perceives US determination "to maintain by all means possible their preeminent position in space" but sees a "contradiction of elevated ambition and fading commitment" on the civil side. Although he does not believe China considers its space program a primary contributor to its "comprehensive national power," the People's Liberation Army, which controls the *entire* Chinese space program, places high priority on cutting-edge technologies to enhance war-fighting capabilities on Earth and in space. Unlike the United States, which has developed most of its own space-related technologies, China has supplemented its indigenous development with Russian-bought technologies and nefariously acquired American technologies.

Section 2 of *The New Space Race* focuses on the space warfare doctrines of the United States and China, with an eye toward deciphering Chinese intent. After enumerating the two countries' present and future military space capabilities, Seedhouse bluntly labels deployment of space weapons "inevitable" and an arms race in space "unavoidable." Such terms generally do not appear in a professional historian's lexicon, and their use should alarm any thoughtful, informed reader who understands that all people can make choices in charting their future. His title for this section, "Dark Arena," is appropriate not for the reason Seedhouse suggests—because of intentionally deceptive statements and behavior on China's part—but because people and governments can be unpredictable.

Factual errors should alarm readers, and Seedhouse includes many in this supposedly up-to-date study. On the American side alone, he discusses Titan II, Titan IV, and Delta II as current US space boosters. Adding to his potential embarrassment, he incorrectly intimates that the Space Tracking and Surveillance System already exists as "the major feature" of the US space surveillance system and that Milstar satellites were heavily used in Operation Desert Storm. Errors of omission, such as failure to mention the Wideband Global SATCOM System, Space-Based Infrared System payloads in highly elliptical orbit, or *TacSat-2*, only compound an informed reader's skepticism regarding the accuracy of other details and, on a higher intellectual level, the wisdom of the author's analysis and conclusions.

After explaining Chinese and American space exploration programs, especially human spaceflight, as "The Second Space Race," Seedhouse advances to his fourth, final section titled "Why Cooperation Won't Work and Why a New Space Race is Looming." It becomes apparent here, if not earlier, that the author has preconceived the notion of a Sino-American space arms race rather than reaching a reasonable conclusion based on careful analysis of all the facts. Near the end of the book, he even contradicts his often-repeated assertions about the inevitability and unavoidability of such a race by bluntly (and correctly) stating, "The point is that it is impossible to predict the future, just as it is impossible to know if or how Sino–US relations might develop" (p. 215). In his next-to-last narrative sentence, he reiterates, "The question of whether an unrestrained military competition in space is about to unfold remains an open one" (p. 230).

Sandwiched between those two statements, however, Seedhouse postulates that China's assertion of sovereignty over Taiwan "ultimately" will define that nation's space warfare strategy and will become the fulcrum of American strategy, putting the two countries "on a collision course" toward an "inevitable arms race in space." Before accepting his premises, assertions, or conclusions, readers would do well to examine other volumes dealing with Chinese space activities, such as Joan Johnson-Freese's *The Chinese Space Program: A Mystery Within a Maze* (1998), Brian Harvey's *China's Space Program—From Conception to Manned Spaceflight* (2004), and Roger Handberg and Zhen Li's *Chinese Space Policy: A Study in Domestic and International Politics* (2007). They might conclude that sometimes, as in the case of *The New Space Race*, a book's title holds more promise than its content delivers and that answering the question of whether China and the United States will be adversaries, peer competitors, or collaborative partners in future space endeavors is not an easy exercise.



Reviewed by Dr. Rick W. Sturdevant, deputy command historian, HQ Air Force Space Command.

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